SR 307 MP 1.34 Unnamed Tributary to Dogfish Creek (991999): Draft Preliminary Hydraulic Design Report

Julie Heilman, PE, State Hydraulics Engineer, FPT20-00157
Y-12554 Olympic Region GEC

PHD LEAD PROFESSIONAL ENGINEER:
Alex Morton, PE, Water Resources Engineer FPT20-10046, GeoEngineers
AUTHORING FIRM PHD QC REVIEWER(S):
Dan Eggers, PE, Associate Water Resources Engineer FPT20-02236, GeoEngineers
OLYMPIC REGION GEC FISH PASSAGE AND STREAM DESIGN ADVISOR (SDA):
Nich VanBuecken, MSCE, PE, FPT20-08789, Jacobs

See details below on roles and responsibilities, approved by HQ Hydraulics August 4, 2022.

LIST OF CONTRIBUTING ENGINEERS, GEOMORPHOLOGISTS, AND BIOLOGISTS:

Morgan McCarthy, Water Resources Designer (FPT20-46668) GeoEngineers
Blake Graffe, Water Resources Designer (FPT20-41356) GeoEngineers
Minda Troost, LG, Fluvial Geomorphologist (FPT20-15856) GeoEngineers
Adam Wright, PWS, Fisheries Biologist (FPT20-17646) GeoEngineers

ROLES AND RESPONSIBILITIES FOR THIS PRELIMINARY HYDRAULIC DESIGN

The roles and responsibilities of the key individuals in developing this Preliminary Hydraulic Design (PHD) are defined as follows for the Olympic Region GEC:

PHD Lead PE
Responsibility: Water Resources Professional Engineer in responsible charge of this Hydraulic Design Report, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices.

Authoring Firm PHD QC Reviewer(s)
Responsibility: Qualified independent individual(s) responsible for the detailed checking and reviewing of hydraulic and stream design documents prepared by the authoring firm, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices. Before submittal to the GEC, the authoring Firm Quality Control (QC) Review shall be performed in accordance with the QC methods identified in the quality assurance document Technical Verification Form. The QC methods are defined in the Olympic Region GEC Quality Management Plan Section 5.3 and the Quality Management Plan Supplement developed specifically for Y-12554 Task AC.

Olympic Region GEC Fish Passage/Stream Design Advisor
Responsibility: Water Resources Professional Engineer providing mentorship, process oversight, quality check issue resolution, and recommendations in the approach to hydraulic analysis and design performed by the **PHD Lead PE**. Before submittal of draft deliverables from the GEC to either the PHD Lead or WSDOT Headquarters, the Olympic Region GEC Fish Passage/Stream Design Advisor will review and refine GEC comments and confirm GEC comment resolution by the **PHD Lead PE**.

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1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 307 crossing of the unnamed tributary (UNT) to Dogfish Creek at milepost (MP) 1.34 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 991999) and has an estimated 8,970 linear feet (LF) of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing using the Unconfined Bridge Methodology. This methodology was selected because the stream exceeded the floodplain utilization ratio threshold of 3.0.

The crossing is located in Kitsap County, 3.5 miles northeast of Poulsbo, Washington, in WRIA 15. The highway runs in a northeast-southwest direction at this location and is about 4,700 feet from the confluence with mainstem Dogfish Creek. UNT to Dogfish Creek generally flows from northeast to southwest beginning approximately 2.5 miles upstream of the SR 307 crossing. A preliminary hydraulic design for another WSDOT crossing on SR 307 milepost 1.45 (ID 991572) is being developed (see Figure 1 for the vicinity map).

The proposed project will replace the existing corrugated steel, 69-foot-long, 4-foot-diameter culvert with a structure designed to accommodate a minimum hydraulic width of 36 feet. The proposed structure is designed to meet the requirements of the federal injunction using the unconfined bridge criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022a).

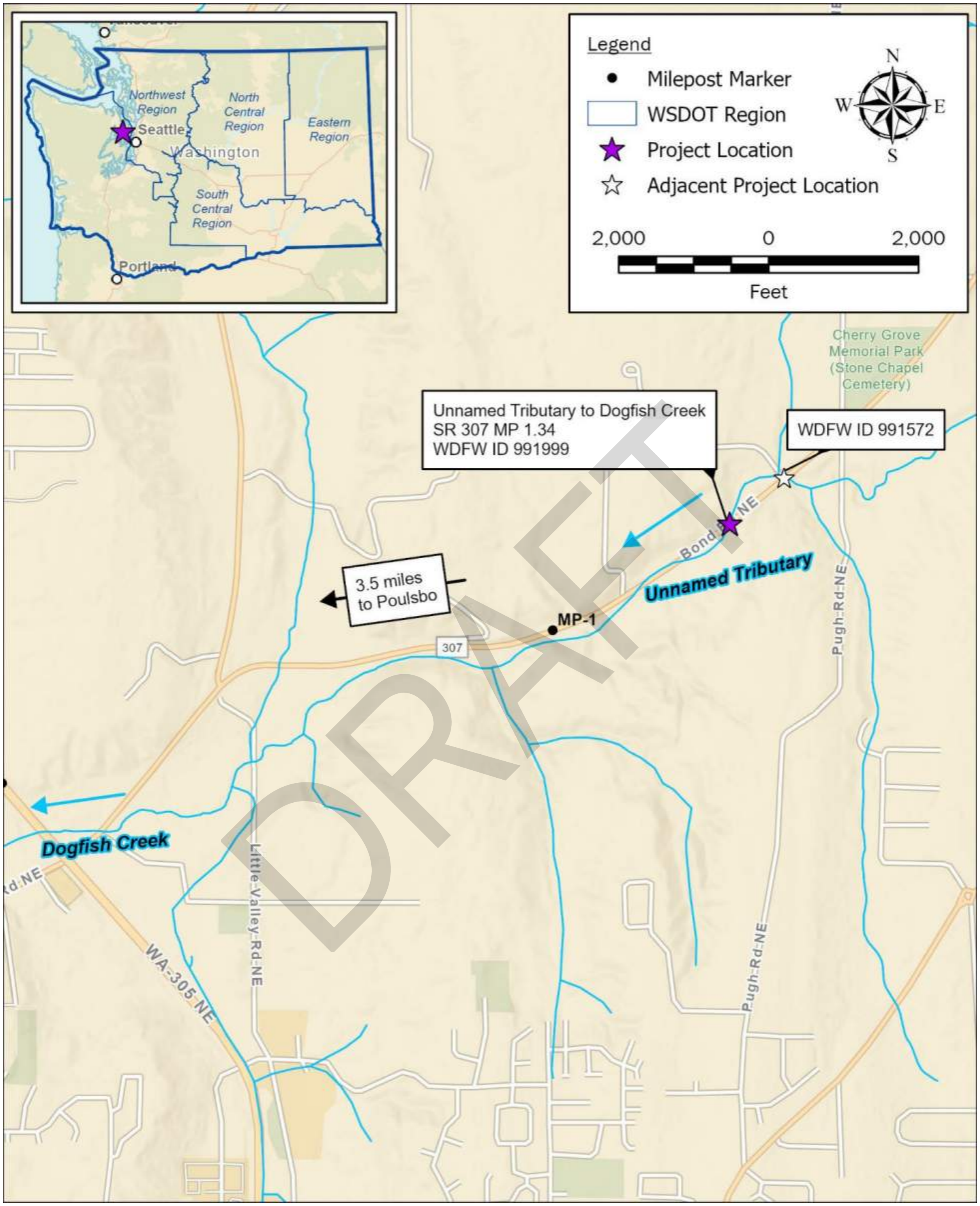

Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW, and past records like observations, maintenance, and fish passage evaluation.

2.1 Site Description

Crossing 991999 was characterized as a partial fish passage barrier (67 percent passability) in 2006 due to an excessive outfall drop of 2.0 feet (WDFW 2022). This perched outlet inhibits upstream migration of adult salmonids and exceeds the State's maximum hydraulic drop requirement (Barnard, et al. 2013). The crossing is a 4.0-foot-diameter, corrugated steel culvert (CST) that conveys UNT to Dogfish Creek 69 feet southwest under SR 307 at milepost (MP) 1.34. Relative to the natural stream channel, the structure is undersized (Culvert/Stream Ratio: 0.37) and unlikely to transport sediment and wood downstream, reducing habitat complexity. Site investigations in December of 2021 confirmed an accumulation of large woody debris at the inlet and an outfall drop of 2.6 feet (Section 2.6.1).

Correction of the 991999 crossing will restore access to up to 8,970 LF of quality rearing and spawning salmonid habitat (WDFW 2022). The site is not designated as a Chronic Environmental Deficiency (CED) and does not have a known history of flooding. Approximately 0.7 miles west of the project site, there is a FEMA regulatory Special Flood Hazard Area (SFHA), mapped as Zone A, along Dogfish Creek. Zone A areas have a 1 percent annual chance of inundation, but no associated base flood elevations or flood depths (WSDOT 2022d). As Built documents illustrate pavement repairs were made at the project area in 1992 (WSDOT 1992), 1998 (WSDOT 1998), and 2009 (WSDOT 2009). No other maintenance history was available at the time of this report.

2.2 Watershed and Land Cover

Crossing 991999 is located on an un-named tributary to Dogfish Creek within WRIA 15 (Kitsap) (Washington Department of Ecology 2020). From its headwaters, UNT to Dogfish Creek flows approximately 2.0 miles before crossing SR 307 at milepost 1.34 (Crossing 991999). After passing though crossing 991999, UNT to Dogfish Creek flows 1.0 mile southwest to Dogfish Creek, which runs 0.8 miles west to Puget Sound. Another culvert (Crossing 991572) is located on UNT to Dogfish Creek approximately 800 feet upstream of the project site.

A watershed with an area of approximately 1,236 acres (1.93 mi^2) drains to the project area (Figure 2). Watershed boundaries were delineated using ArcGIS Pro version 2.9.0 and Kitsap County OPSW LiDAR dataset (3m) from 2018 (Datum North American 1983 HARN) (WSDNR 2022). The watershed delineation was coordinated with the design team for upstream crossing 991572 to ensure consistency between the two sites. Approximately 8 additional acres of land drain to crossing 991999 that were not included in the crossing 991572 design.

Two tributaries join UNT to Dogfish Creek from the north and south at approximately 0.12 and 0.21 river miles (RM) upstream of the project location, respectively (Figure 2). The basins of the two tributaries contribute approximately 35 percent of the total watershed area draining to the project area.

Based on LiDAR, the watershed area upstream of the project crossing has a maximum elevation of 479 feet and minimum elevation of 134.5 feet (WSDNR 2022). WSDOT's survey of crossing 991999 reports an inlet invert elevation of 132.38 feet NAVD88 and an outlet elevation of 132.43 feet NAVD88.

Land cover in the basin (Figure 3) was summarized using the National Land Cover Database (NLCD 2019). Deciduous, Evergreen, and Mixed Forested land covers approximately 41 percent of the basin. Developed land covers 30 percent, ranging from open space to high intensity. The remaining 29 percent is inhabited by cultivated, herbaceous, shrubland, and barren land (Table 1). Approximately 7 percent of the delineated basin is impervious (See Section 3).

Table 1: Land cover (NLCD 2019)

Land cover class	Basin coverage (percentage)
Developed	30.4
Forested	40.9
Wetland	8.5
Barren Land	0.2
Shrub/Scrub	4.1
Herbaceous	7.0
Hay/Pasture	9.0

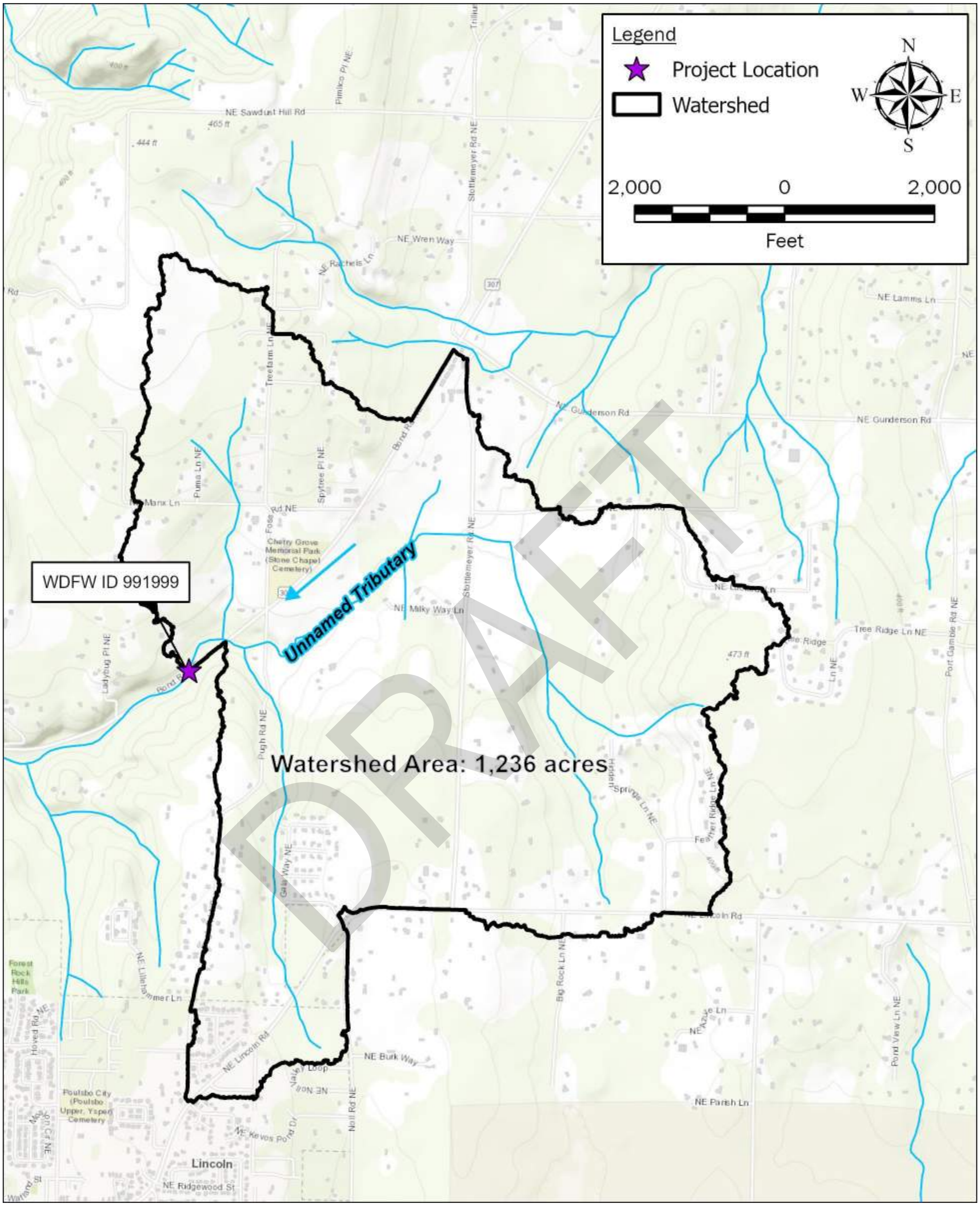

Figure 2: Watershed map

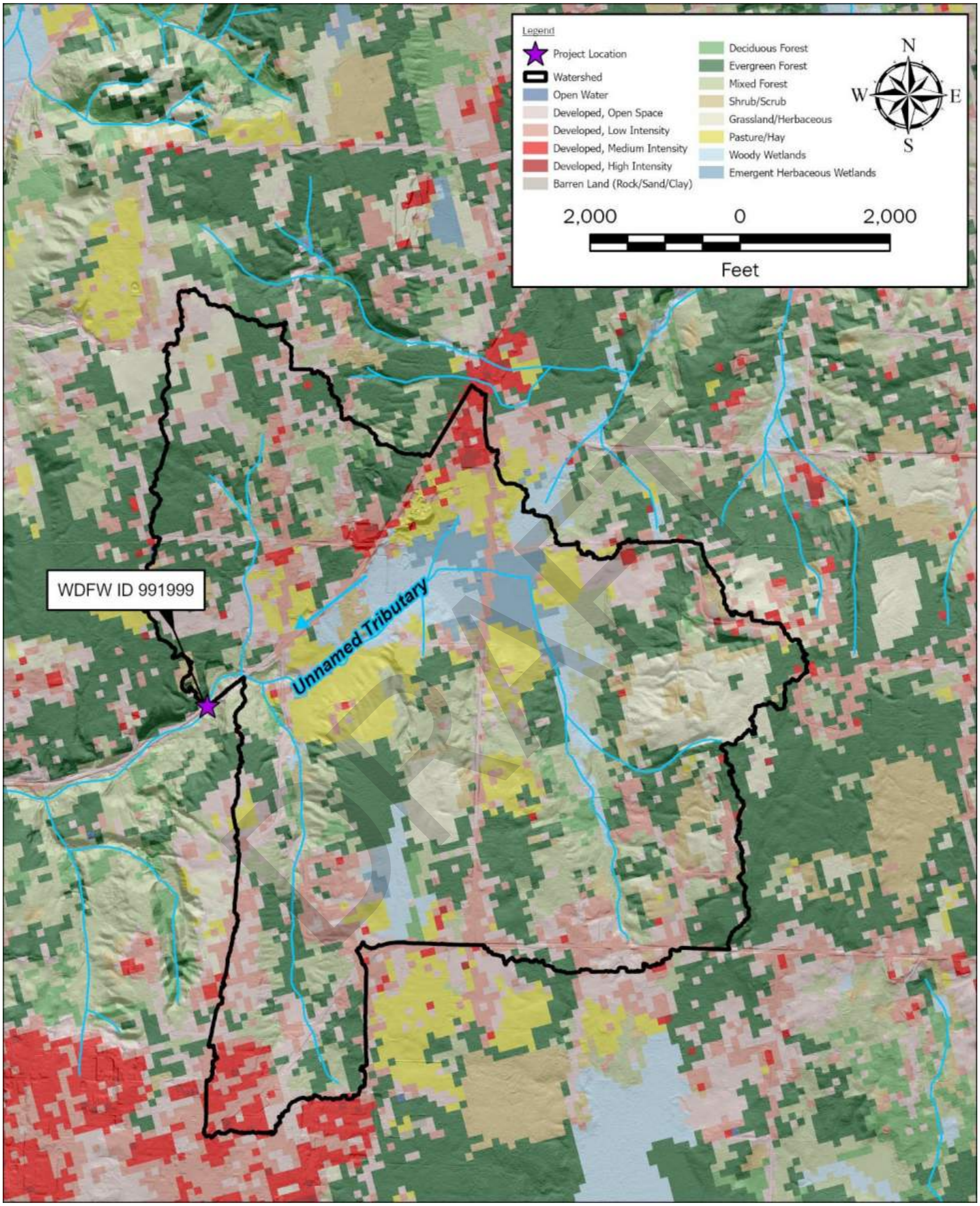

Figure 3: Land cover map (NLCD 2019)

2.3 Geology and Soils

Geology of the Puget Lowland and the project site is mapped as Vashon till (Qvt) in Yount, et al. (1993). The Washington Geological Survey utilizes this mapping within the Washington Geologic Information Portal (Washington State Geological Survey 2019) but has changed the description and unit label to Pleistocene continental glacial till and Qgt respectively (Figure 4). Vashon till, is a non-stratified composite of sand, silt, clay, gravels, cobbles, and boulders that was deposited beneath the Vashon glacier. It generally exhibits low permeability, which can influence peak flows and runoff. Its higher presence of fines can make the operation of equipment difficult if there is a lot of moisture in the area.

Soil data from one boring located on the shoulder of SR 307 indicates road fill down to the approximate elevation of the channel bed (WSDOT 2022d). Fine-grained glacial deposits of poorly graded sand with silt are recorded below this elevation, which would not hinder lateral channel migration. No bedrock was recorded within the 41 feet of depth of the boring.

Published geologic hazard areas in the project vicinity include erosion, seismic, landslide, and steep slope hazards (Kitsap County Department of Community Development GIS Division 2022). The Hood Canal fault zone is approximately 8 miles west of the project site, the southern Whidbey Island fault zone is approximately 11 miles east and the Seattle fault zone is approximately 10 miles to the south (WSDOT 2022d). There are no geologic hazard concerns that need to be addressed in the design. Constructability concerns include site access due to steep slopes, traffic control with limited shoulder space, and liquefaction (WSDOT 2022d).

Soils in the northwest portion of the project watershed (Figure 5) consist of a gravelly ashy loam and a very gravelly sandy loam which drain moderately well (Natural Resources Conservation Service 2022) (Washington State Geological Survey 2019). In the south and headwaters of the project stream, soils consist of a gravelly ashy sandy loam and ashy fine sandy loam which promote decent drainage properties as well. These properties help to attenuate open channel peak flows in the stream.

As UNT to Dogfish Creek flows northwest and crosses between Stottlemeyer Rd NE and SR 307, there are approximately 71 acres of muck-like soils with very poor drainage capabilities. This can intensify peak flows in duration and frequency. Once the stream flows down through Crossing 991999, the soils consist of a sandy loam, which can lead to somewhat excessive draining and higher susceptibility to erosion.

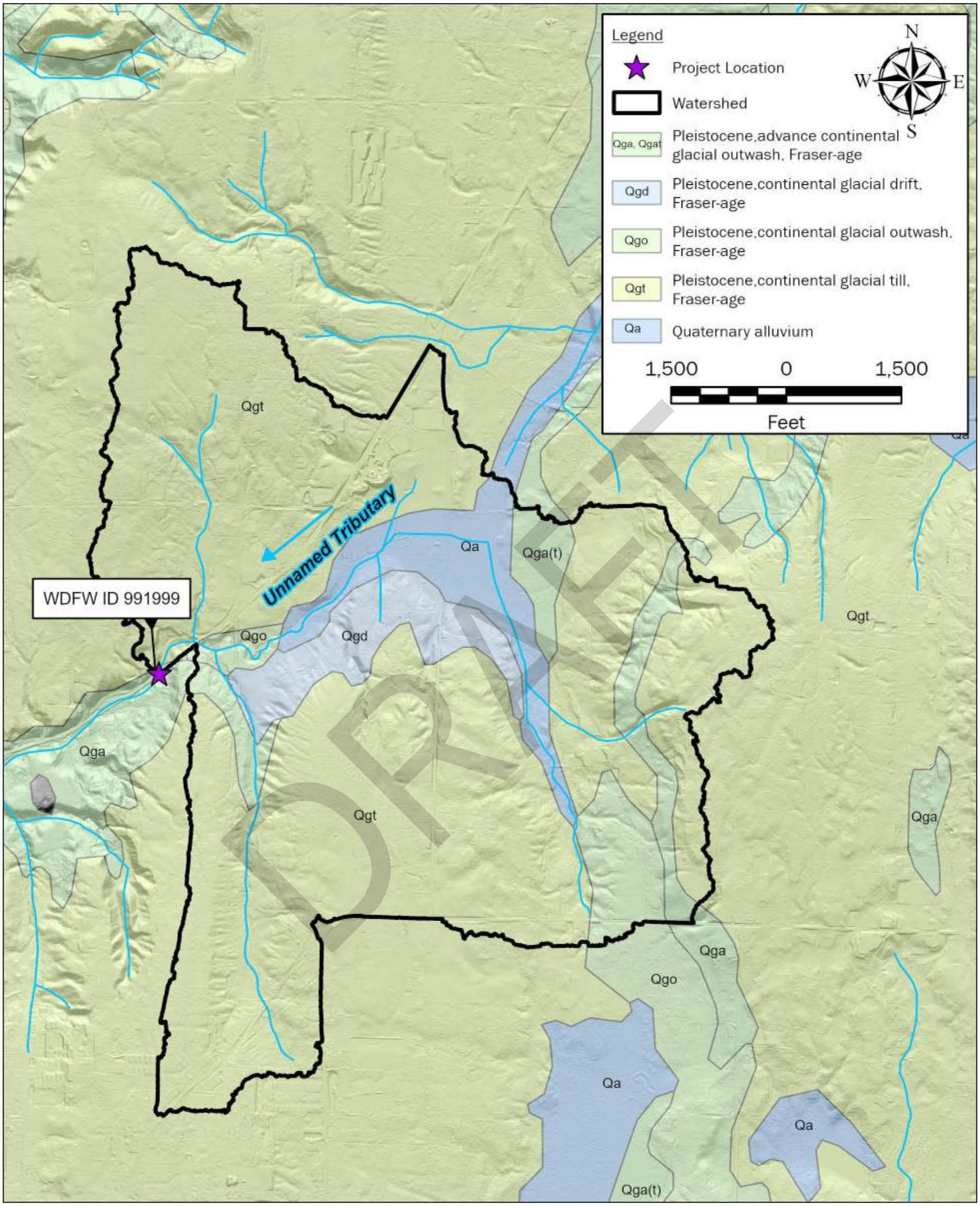

Figure 4: Geologic map

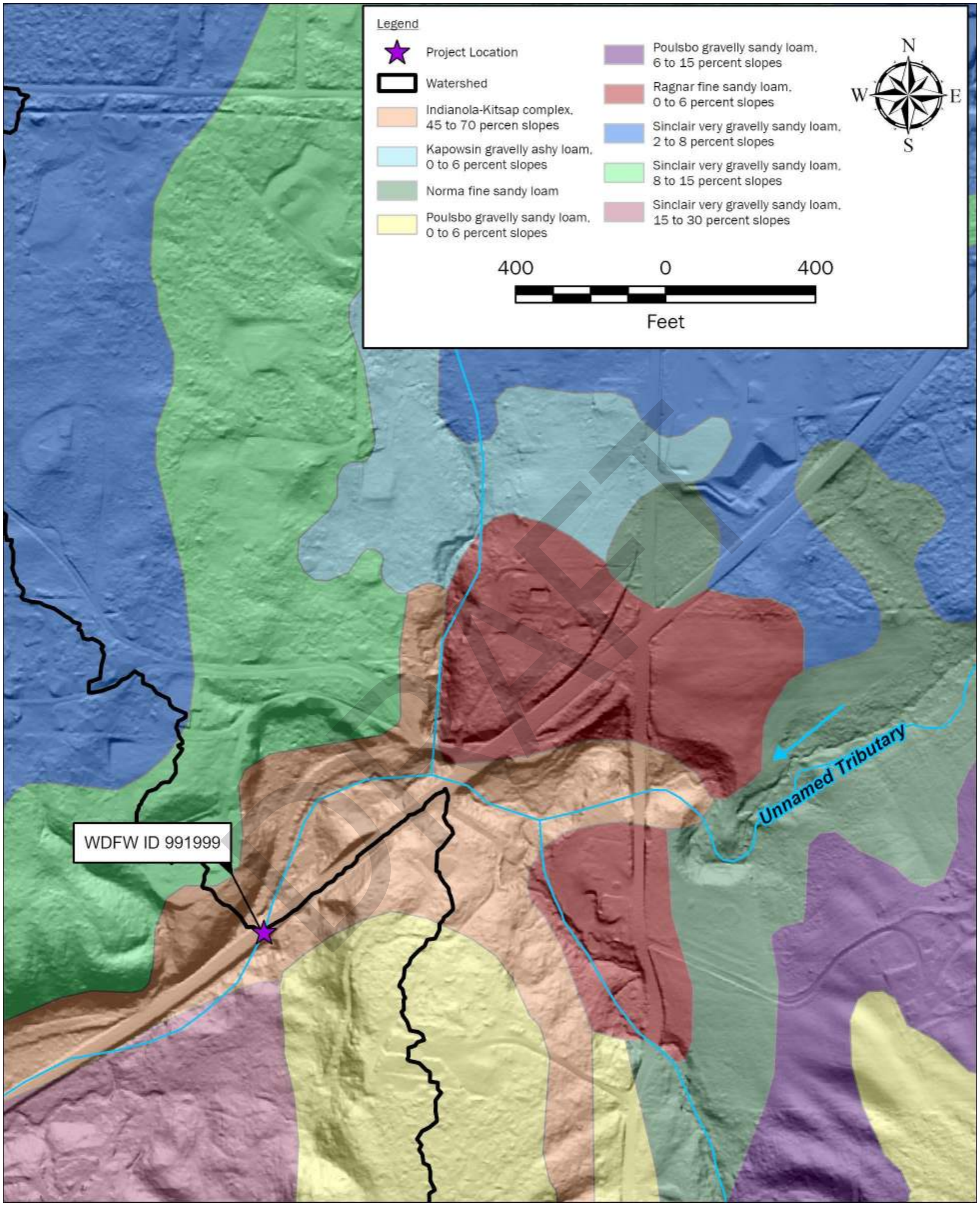

Figure 5: Soils map

2.4 Fish Presence in the Project Area

Fish distribution information was gathered from the Statewide Washington Integrated Fish Distribution (SWIFD) database managed by WDFW and the Northwest Indian Fisheries Commission (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2018) and WDFW Barrier Inventory and Assessment (WDFW 2022).

The predominant species found in Dogfish Creek include Coho (*Oncorhynchus kisutch*), chinook (*O. tshawytscha*), and chum salmon (*O. keta*). A Kitsap County Basin Assessment performed in 1997 reported that the Suquamish Tribes was stocking Dogfish Creek with Chinook and Chum salmon at the time of the study (Kitsap Public Utility District 1997). WDFW Fisheries Biologists surveyed the site in 2010 and deemed the habitat appropriate for the following species: Chum, Chinook, Coho, Steelhead (*O. mykiss*), and Cutthroat Trout (*O. clarkii*).

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Fall Chum	Documented	SWIFD (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2018)	Not warranted
Fall Chinook (Downstream)	Documented	SWIFD (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2018)	Threatened – Puget Sound ESU
Coho	Documented	SWIFD (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2018)	Not warranted
Winter Steelhead	Documented	SWIFD (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2018)	Threatened – Puget Sound DPS
Sea Run Cutthroat Trout	Documented	SWIFD (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2018)	Not warranted
Resident Cutthroat Trout	Documented	SWIFD (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2018)	Not warranted

2.5 Wildlife Connectivity

The 1-mile-long segment that Site ID 991999 falls in was not ranked for Ecological Stewardship and was ranked low priority for Wildlife-related Safety by WSDOT Headquarters (HQ) ESO. Adjacent segments to the north and south ranked medium and low. A wildlife connectivity memorandum will not be provided at this site and additional width or height has not been recommended by WSDOT HQ ESO for wildlife connectivity purposes.

2.6 Site Assessment

2.6.1 Data Collection

The interdisciplinary GeoEngineers team conducted a field-based site assessment on December 10, 2021. A concurrence site visit was attended on February 2, 2022, by WSDOT, comanagers, and the PACE design team responsible for fish barrier replacement design of crossing 991572. GeoEngineers was not present during this assessment, which spanned the reach downstream of 991572 to the inlet of 991999. Information regarding this meeting such as bankfull width measurement locations, reference reach concurrence, and general design discussion were coordinated between the PACE and GeoEngineers design teams.

GeoEngineers' data collected for this crossing included bankfull width measurements, site observations, Wolman pebble counts, Manning's roughness observations, the project complexity checklist, creek habitat and geomorphic assessment, and cross-sectional information using an auto level. Field assessment by the design team extended approximately 400 feet upstream and downstream of the 991999 crossing.

A full field report for the design team site visit is included in Appendix B. Bankfull width measurements collected during both the design team and concurrence team field visits are provided in Section 2.7.2 and Table 3, Wolman pebble counts are summarized in Section 2.7.3 and Table 5, and Manning's roughness calculations are discussed in Section 5.1.3 and summarized in Table 12. Habitat, large woody material (LWM), and general site observations are presented in the following subsections characterizing existing conditions. The spatial distribution of data collection is shown in Figure 6.

A topographic survey of the project site, provided in February 2022, was conducted by WSDOT and was used in conjunction with site visit observations to assess the project site existing conditions and inform the preliminary hydraulic design. Detailed survey information provided by WSDOT extends from upstream of the 991572 crossing to approximately 260 feet downstream of the crossing 991999 outlet. The downstream boundary of the detailed survey is just upstream of a debris jam spanning the channel creating a roughly 5-foot drop. The survey was supplemented with the 2018 Kitsap OPSW LiDAR dataset (WSDNR 2022).

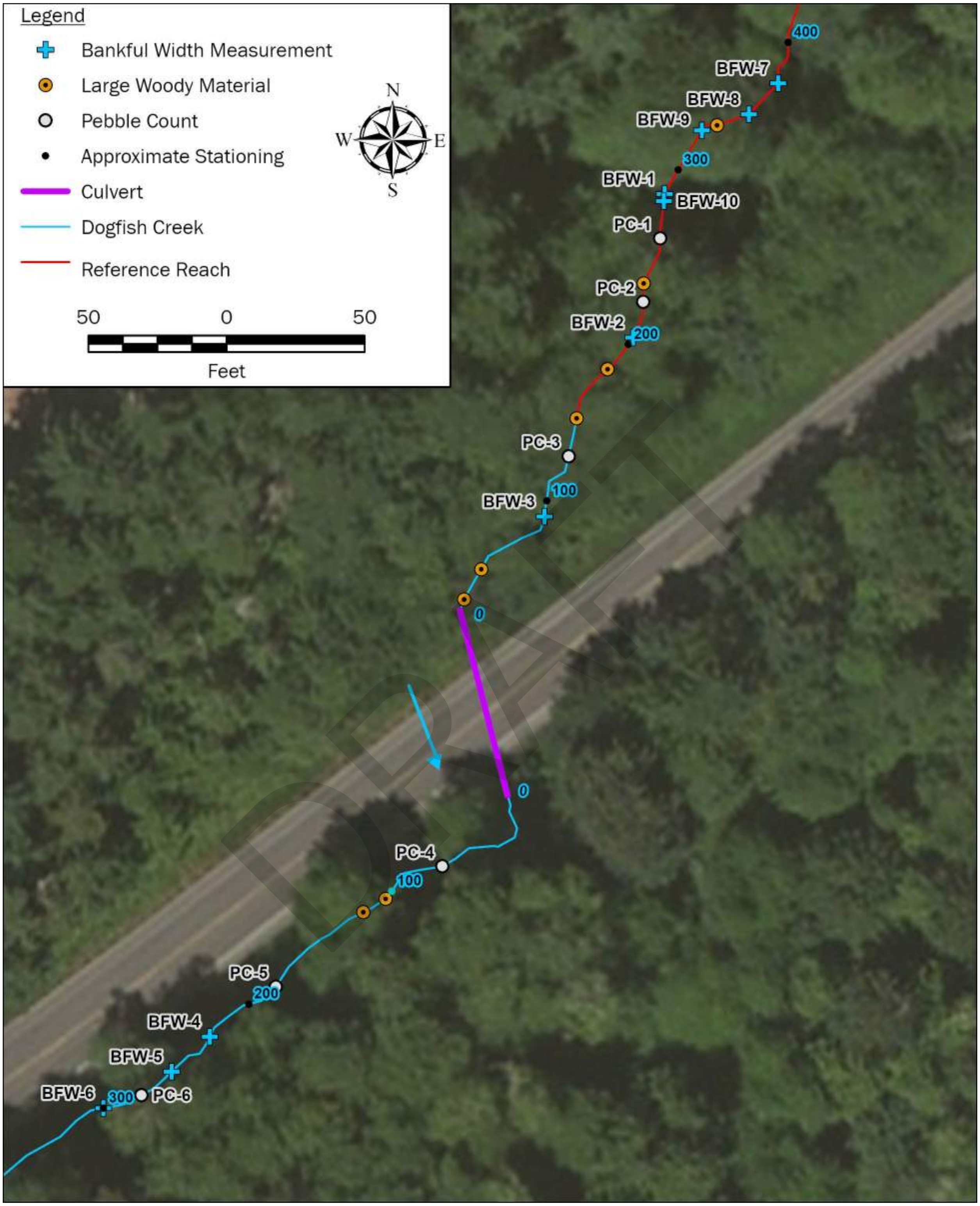

Figure 6: Reference reach, bankfull width, and pebble count locations with distance from crossing noted

2.6.2 Existing Conditions

Crossing 991999 conveys Dogfish Creek south under SR 307 at milepost 1.34. The crossing itself and downstream are within WSDOT right-of-way, while the stream upstream of the crossing is on private property. The area in the immediate vicinity of the crossing is well forested in an area of rural development. Upstream of the project site, Dogfish Creek runs parallel to SR 307 until it flows north through the crossing 991572 culvert. Then it proceeds parallel to SR 307 until it takes a 90-degree turn to the south and enters the crossing 991999 culvert. Dogfish Creek enters and exits the culvert through a 4-foot-diameter CST of approximately 70 feet in length. Downstream of crossing 991999, the reach runs parallel to SR 307 while confined between SR 307 embankment and the valley wall until end of project reach. Three as-builts were obtained, illustrating pavement repairs in the project area in the years 1992 (WSDOT 1992), 1998 (WSDOT 1998), and 2009 (WSDOT 2009).

The culvert inlet has a wingwall that extends 2.5 feet laterally from the right side of the culvert inlet along the SR 307 roadway embankment, which includes riprap and presumably naturally deposited toe logs. No signs of burial, chaining, or other indications of manual placement of these logs were observed.

Woody material, ranging in size from approximately 12 to 18 inches in diameter, has accumulated at the culvert inlet and has partially blocked the inlet forcing a small water surface drop into the pipe, indicating that maintenance at this location has not occurred in the recent past. The culvert inlet's visibility was mostly obstructed by this accumulated timber as shown in Figure 8. Obvious signs of cut/felled logs were not observed. Immediately upstream of the inlet, Dogfish Creek is confined between the SR 307 roadway embankment on the left bank and an abandoned roadway on the right bank. This abandoned roadway forces the creek to turn 90 degrees into the inlet of the crossing. Dogfish Creek was backwatered along the abandoned roadway for a short distance as shown in Figure 9 and Figure 10, presumably due to the constricted flow into the culvert associated with channel alignment, confinement between the highway and abandoned road, undersized crossing, and the woody material obstruction.

Upstream of the culvert inlet, a gravel bar on the right bank forces sinuosity in creek flow approximately 12 to 22 feet upstream from the culvert inlet (see Figure 13). Directly across the bank from the culvert inlet, large riprap was observed with toe logs stacked against it as pictured in Figure 14. The riprap and toe logs appear to be manmade for the purpose of bank erosion control. Buried immobile LWM were found approximately 59 feet upstream from the inlet, forcing a pool-riffle morphology (Figure 15). Further upstream, the channel splits between a main flow channel and a high flow channel (Figure 16). Each channel has channel-spanning LWM. One hundred twenty-nine feet upstream lies additional channel spanning LWM sitting approximately 1 to 2 feet above the water surface. A sand bar spans approximately 165 to 181 feet upstream of the culvert followed by channel spanning LWM of 4.5-inch diameter (Figure 17). Approximately 236 feet upstream of the culvert is another channel spanning log with its rootwad engaged with the creek. The LWM is engaged for the entire width of the channel forcing a riffle pool morphology (Figure 18). Three hundred thirty feet upstream, channel spanning LWM sits above the water surface (Figure 19).

The outlet of crossing 991999 was above the channel with a 0.8-foot water surface to water surface drop measured at the outlet (Figure 20). This water surface drop from the culvert limits fish passage as it forces the fish to jump into the pipe culvert to access the habitat upstream of the crossing. This issue combined with the low water depth running through the pipe limits the percent passability of the crossing to 67 percent (WDFW 2022). The outlet has no wingwalls or a headwall. The flow exiting the outlet forms a scour pool of approximately 20 feet wide and 3 feet maximum depth at time of site assessment. Based on LiDAR data, Dogfish Creek maintains a consistent slope of approximately 1.8 percent throughout the project reach along the thalweg from upstream to downstream including the crossing itself (see Figure 41). No sediment was observed inside the culvert during site assessment.

Downstream of the culvert outlet, the channel was confined between the SR 307 embankment and a valley wall (Figure 12, Section 2.7.2). Along the SR 307 embankment, occasional large riprap engages with the channel flow (Figure 21). Dogfish creek continues downstream with riprap forced steps (Figure 22) that appear manmade. Farther downstream, LWM partially engages with the channel forcing a step-pool morphology before the downstream end of project reach (Figure 23).

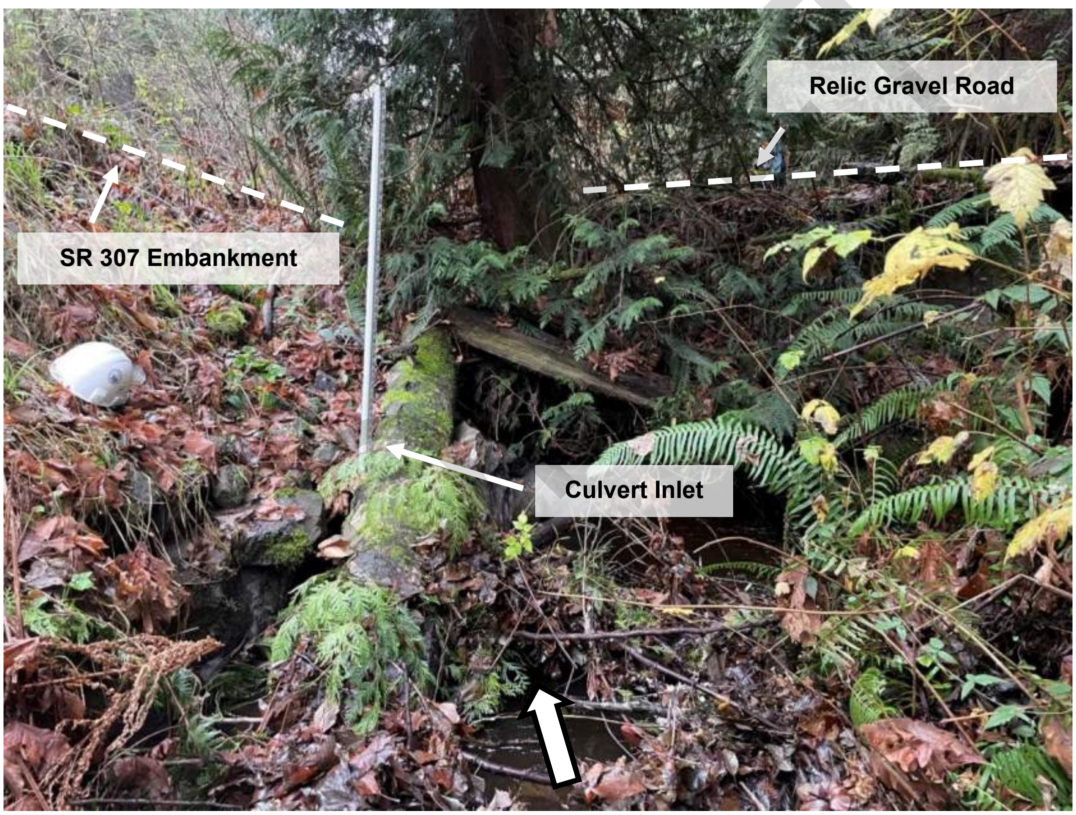

Figure 7: Woody debris racked at 991999 inlet

Figure 8: Close-up of 991999 inlet

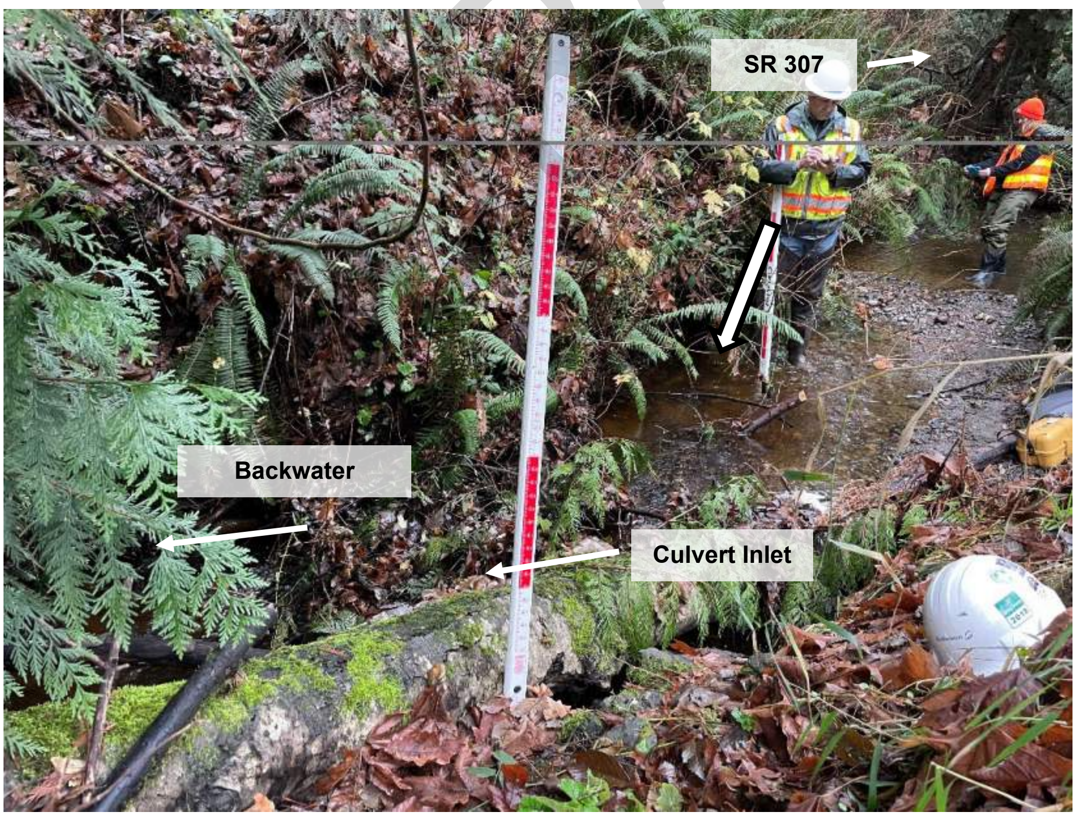

Figure 9: Dogfish Creek at culvert inlet looking upstream

Figure 10: Backwater along the abandoned roadway

Figure 11: Confined creek downstream of culvert

Figure 12: Confined creek continues downstream of culvert. Boulders interact with the channel along the right bank


Figure 13: Gravel bar 12’ to 22’ upstream from culvert inlet looking upstream

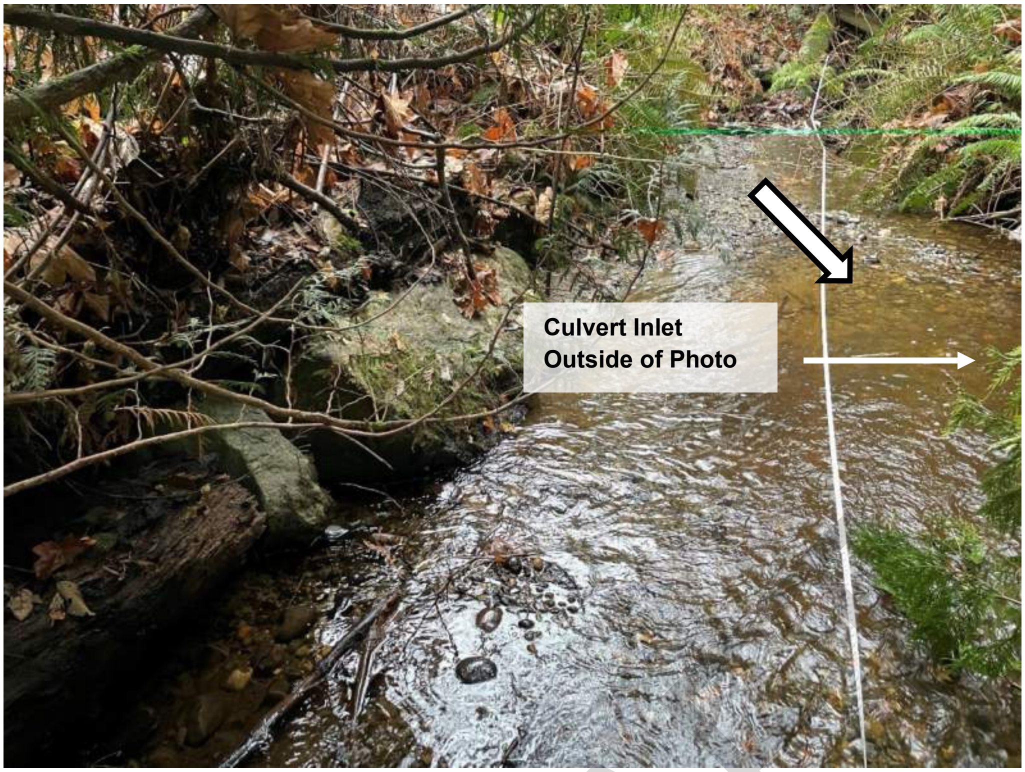

Figure 14: Large riprap with toe logs stacked against them on opposite bank from culvert inlet


Figure 15: Buried immobile LWM forcing a pool riffle morphology

Figure 16: UNT Dogfish Creek split into a main channel and high flow channel with channel spanning LWM

Figure 17: Sand bar with 4.5-inch diameter channel spanning LWM

Figure 18: Channel spanning LWM with rootwad engaged with creek channel

Figure 19: Channel spanning log 330 feet upstream of the crossing inlet

Figure 20: Crossing 991999 outlet

Figure 21: Large riprap on right side of channel looking downstream

Figure 22: Riprap forced steps downstream of crossing 991999

Figure 23: LWM forced step downstream of crossing 991999

2.6.3 *Fish Habitat Character and Quality*

Aquatic habitat was assessed by the design team during site visit 2 (December 2021) both upstream and downstream of crossing 991999 (Appendix B).

Upstream of crossing 991999 provides high-quality fish habitat consisting of ample amounts of wood, deep pools, spawning gravel and occasional overbank floodplain areas that are active at higher flows. Fish habitat within the assessed reach appeared suitable for spawning with patches of spawning gravels at most riffle crests/pool tailouts and throughout the full length of numerous riffles in the reach. Some gravel bars may be suitable for steelhead and cutthroat spawning in the spring when flows are higher (Figure 33). In-channel wood has created various micro habitats consisting of diverse velocity regimes and water depths, excellent for juvenile rearing (Figure 18). LWM jams led to the development of several deep pools with instream cover suitable for adult holding during migration and spawning in addition to use by juvenile or resident specimen (Figure 24). The deep pools formed from instream wood were frequently in proximity to potential spawning habitat. At several locations the banks were undercut providing cover from predators. The reach has good overbank and canopy cover from surrounding dense vegetation providing nutrients for macroinvertebrates and shade during summer months. Given the geomorphic setting, low overbank areas upstream of the crossing could support wetland conditions; however, obligate wetland vegetation or wetland hydrology (surface saturation or inundation) were not observed.

The reach downstream of crossing 991999 appeared to provide lower-quality adult and juvenile salmonid habitat due mainly to the more continuous, direct impacts associated with its proximity to SR 307 (Figure 12). The downstream reach has less woody material and no sinuosity in the channel, and consequently less instream complexity. Submerged cover was generally limited to larger boulders, apparently mobilized from along the right bank, or smaller pieces of mobile wood. Proximity parallel to the roadway toe also limits vegetation cover and floodplain refuge along the right bank; similar conditions were observed along the left bank although this feature was not obviously manipulated. These constrictions limit the potential for off-channel wetlands to develop. There were occasional patches of spawning gravels in the downstream reach, often located at the crest of riffles. Approximately 330 feet downstream there was an accumulation of LWM in the channel consisting of several large logs and a large quantity of smaller woody debris (Figure 43). The blockage has an approximate 5-foot water surface elevation drop with a short area of ponded water on the upstream side and likely blocks fish passage upstream in its current configuration.

Figure 24: Gravel bar built up in hydraulic shadow of large rootwad, splitting flow

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

Upstream of the project site, the riparian area is primarily comprised of salmonberry (*Rubus spectabilis*), sword fern (*Polystichum munitum*), spreading wood fern (*Dryopteris expansa*), western red cedar (*Thuja plicata*), and big leaf maple (*Acer macrophyllum*). Cedar and maple are ideal candidates for recruitment, as they tend to have lower decay rates compared to other species (NRCS 2007). One small patch of invasive archangel (*Lamiastrum galeobdolon*) was found along the stream bank. Canopy cover in the reference reach was estimated to be 75 percent during the site visit performed in December of 2021 (Figure 26 and Appendix B).


Figure 25: Wind thrown western hemlock approximately 300 feet upstream of existing culvert

Figure 26: Canopy cover observed in upstream riparian corridor

Downstream of the 991999 crossing, NE Dogfish Creek flows adjacent to the SR 307 road prism through a forested area. Right bank vegetation is limited due to the SR307 road embankment (Figure 27). The left channel banks are vegetated with salmonberry, youth-on-age (*Tolmiea menziesii*), and sword fern. The overstory predominately consists of red alder (*Albus rubra*), western red cedar, and western hemlock (*Tsuga Heterophylla*).

Figure 27: Riparian vegetation limited on rank bank (downstream orientation) due to SR 307 road embankment

Ample woody material was present upstream of crossing 991999. Woody material in the upstream reach engaging with flow consisted of both smaller mobile woody material (short and/or narrow logs and large deciduous branches, see Figure 30) and larger key pieces. Larger key pieces were observed racking smaller mobile woody material at several locations in the upstream reach leading to the development of LWM channel spanning jams and downstream scour pools. The woody material present in the upstream reach contributed to the development of channel complexity and a large diversity of micro habitats.

A small woody material jam was located approximately 45 feet upstream of the culvert inlet consisting of mobile woody material racked on one channel-spanning log approximately 8 inches in diameter and two additional logs 10 to 12 inches in diameter extending into the channel from the banks (Figure 30). A single 16-inch channel spanning log partially buried in the channel bed was observed approximately 58 feet upstream of the culvert creating a forced riffle pool (Figure 15). A second LWM jam was observed approximately 150 feet upstream of the culvert inlet consisting of several key members and racking material. The jam appears to have led to the development of a high flow side channel on the left bank (Figure 29). One hundred eighty-two feet upstream of the culvert a 4.5-inch-diameter wood piece was observed spanning the channel (Figure 18). A third large wood jam was observed 235 feet upstream of the culvert (Figure 19). The jam consisted of a 16-inch-diameter root wad with additional racking members. The structure created a scour pool with a water depth of 2.2 feet. Approximately 330 feet upstream of the culvert was an immobile channel spanning log approximately 18 inches in diameter wedged between two trees on the right bank (Figure 19). The large key piece is potentially above the 100-year flood water surface elevation and had an average low chord approximately 3 feet above the channel thalweg.

Due to its inability to effectively transport wood, there is less LWM downstream of crossing 991999 compared to upstream. Woody material was observed partially obstructing the culvert outlet and engaging with flows in the large pool at the culvert outlet (Figure 28). Additional LWM was observed extending into the channel from both banks 108 to 119 feet downstream of the culvert outlet ranging from 9 inches to 12 inches in diameter (Figure 23). There is limited potential for additional recruitment of woody material from the right bank due to the proximity of the channel to the roadway embankment.

Research conducted in the Lowland Puget Sound area found that despite the influence floods have on wood mobilization, it has little influence on recruitment into stream channels (Booth and Fox 2004). Windthrow is likely the significant source of LWM recruitment within the project vicinity (Figure 25).

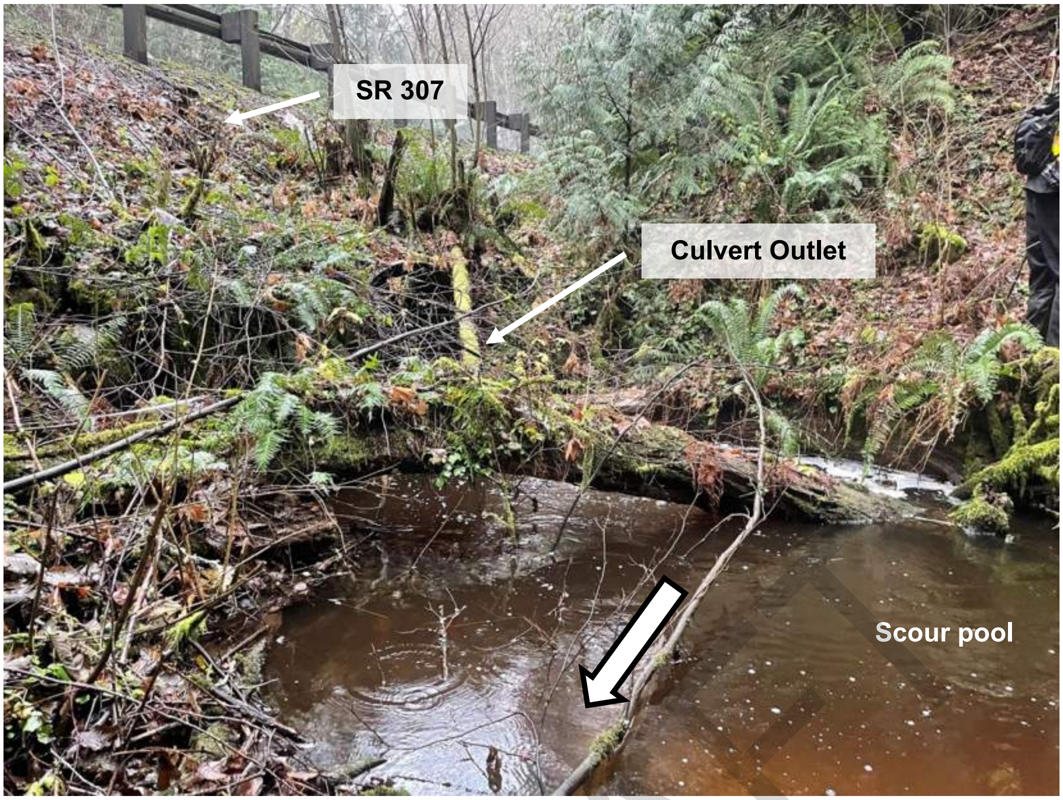

Figure 28: LWM located directly downstream of existing culvert outlet

Beaver activity was not noted during field investigations; however, the probability of beaver activity is moderate in the upstream reaches of the project area due to average channel width, stream gradient, and valley width. Research conducted in the Pacific Northwest has found that channel widths between 10 and 14 feet, stream gradients below 3 percent, and valley widths greater than 150 feet are ideal indicator of intrinsic potential for beaver habitat (Dittbrenner, et al. 2018). Kitsap County's Department of Community Development substantiates this with a beaver habitat suitability GIS map published in 2021, which shows high suitability in the private parcels surrounding the project area (Kitsap County 2021).


Figure 29: Channel spanning LWM in the high flow channel approximately 129 feet upstream of existing culvert


Figure 30: LWM complex approximately 45 feet upstream of existing culvert

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the geometry and cross sections of the channel, and stability of the Dogfish Creek channel both laterally and vertically.

2.7.1 Reference Reach Selection

Desktop review of available information and analysis of the longitudinal profile and planform based on LiDAR data was completed prior to the December 2022 fieldwork to inform reference reach selection. Survey data were not available prior to fieldwork. The long profile indicated a proposed slope through the crossing would likely be within a range near 1.8 to 2.0 percent (Figure 31). The stream was evaluated both upstream and downstream of the crossing for similar slopes and degree of impact by infrastructure to help identify potential reference reaches.

The section of the creek downstream of the crossing, between river stations 7350 and 7850 in Figure 31, appeared unconfined in plan view but was eliminated from consideration due to significant differences in slope. The reach immediately downstream of the crossing (stations 8100 to 8400 in Figure 31) appeared highly confined and impacted by the encroachment of SR 307 and was therefore eliminated from consideration. The creek beyond 750 feet upstream (station 9200) of the crossing was eliminated from consideration due to differences in hydrology and further impacts from infrastructure.

The creek immediately upstream of the crossing, outside the immediate influence of the culvert, has a similar slope to what was expected through a new crossing. Although it lies between the current highway and an old road bed and is partially affected by backwater of the existing crossing at high flows, it has an area of wide floodplain where the entire channel is unimpeded and free to move about. This reach was evaluated during the design team site visit and appeared to be a suitable reference with channel planform, bed morphology and habitat features that provide reasonable representation of natural conditions (Figure 31 and Figure 32). The design team assessed reference reach begins approximately 80 to 85 feet upstream of the culvert inlet near where the stream moves away from the road embankment and the left floodplain widens. It ends approximately 330 feet upstream of the inlet (Figure 31) near a large channel spanning log resting about 3 feet above the channel bed. The design team reference reach ended here based on a change in sinuosity farther upstream.

The co-manager team reference reach designated during the concurrence site visit for crossing 991572 features mostly similar channel geometry and overbank conditions compared to the 991999 design team's assessed reference reach. It overlaps over half of the design team reference reach, shifted approximately 100 feet farther upstream. Utilizing shared bankfull widths and pebble count information as proposed for both SR 307 crossings in this area should provide beneficial alignment between the designs.

While the reach located between crossings 991999 and 991572 appeared to exhibit natural channel conditions, it does appear at least partially influenced by both crossings. Backwater was observed (Figure 10) and modeled (Section 5.2) upstream of the 991999 crossing, and the surveyed channel profile between these two crossings depicts minor sediment aggradation and degradation upstream and downstream of these two crossings, respectively. Note that the apparent potential sediment accumulation area visible on the LIDAR profile (Figure 31) is much less pronounced on the surveyed thalweg (Figure 41). Despite these complexities the reach still appears to demonstrate the best available example of functioning natural channel processes and fish habitat for both crossings. Abrupt changes in slope, sediment size, LWM, or channel geometry were not observed within either the design team or concurrence visit reference reaches.

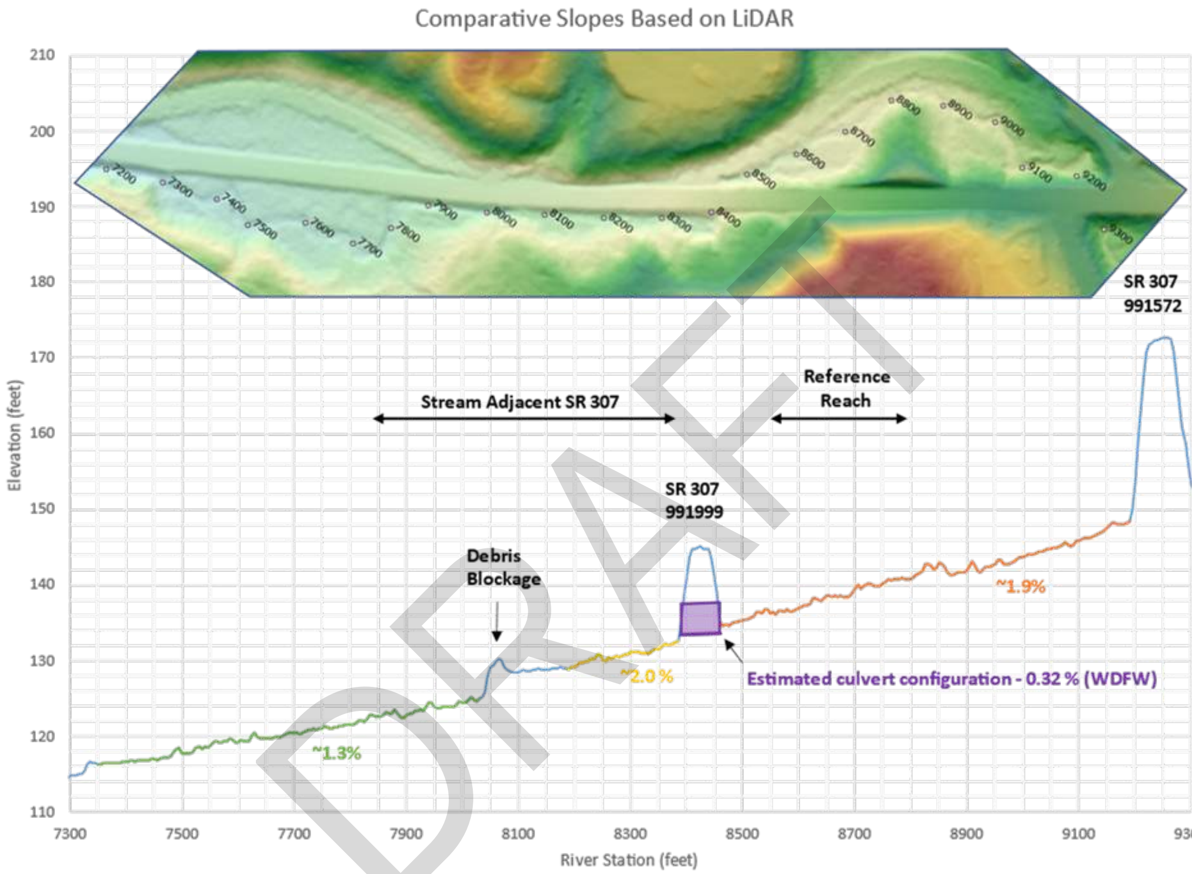

Figure 31: Reference reach location along profile and nearby stream gradients and plan view

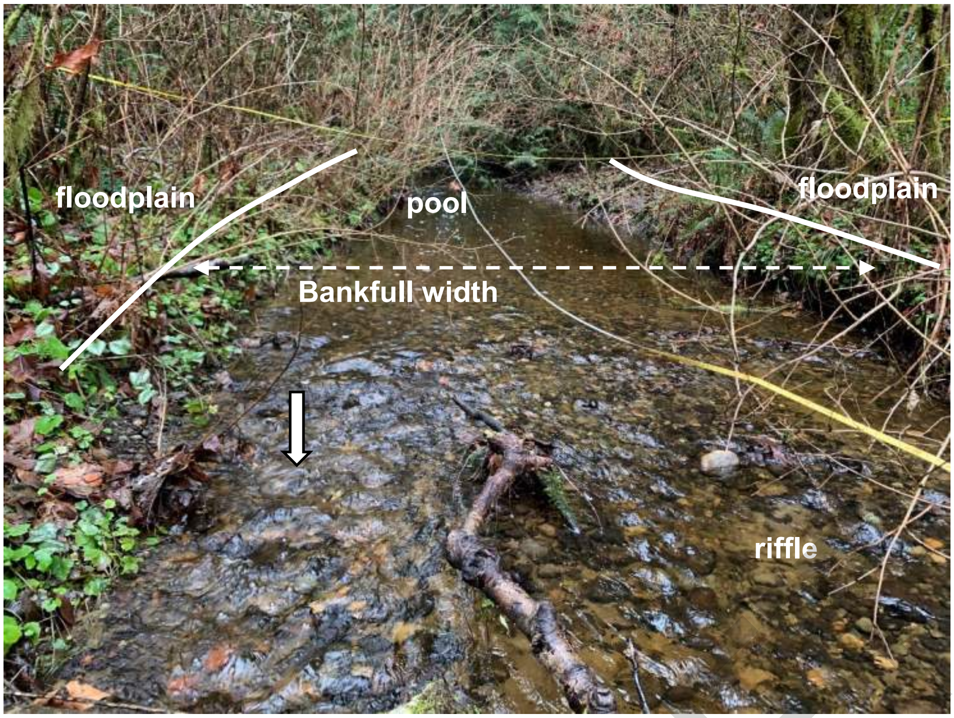

Figure 32 Representative reference reach conditions

2.7.2 Channel Geometry

UNT to Dogfish creek is generally straight through the reference reach but elsewhere exhibits greater sinuosity (Figure 31). The creek in the reference reach is a mix of pool-riffle and forced pool-riffle bedform (Figure 32) at about a 1.8 percent slope measured from survey between top of riffle and top of riffle within the reach. This is the slope to which the design will be compared. This gradient is slightly different than that being utilized for the upstream crossing presumably due to slight differences in extents of reference reach or locations where slopes were measured.

Valley bottom widths in the reference reach range from 30 to 60 feet wide. The channel ranges from moderately confined to unconfined in the reference reach based on the geomorphic definition of confinement which is the ratio of the valley bottom width to the channel width (Legg and Olsen 2015). A stream with a ratio less than 2 is confined, a ratio of 2 to 4 is moderately confined and a ratio greater than 4 is unconfined. Outside the reference reach, valley bottom width decreases in the downstream direction and the channel is confined for about 70 feet before entering the culvert. As the creek exits the culvert, it immediately turns 90 degrees down valley to flow in an artificially straightened channel with little to no floodplain where it is confined between the valley wall and SR 307 (Appendix D). The confinement upstream can be relieved but downstream poses challenges for design of the crossing with a skew in order to soften the turn on the downstream side and transition from less confined to the highly confined condition downstream of the crossing (Section 4.1.2).

Six bankfull widths were measured by the design team during the December 2021 site visit. BFWs 1-3 were measured upstream of the inlet while BFWs 4-6 were measured downstream of the outlet (Table 3, Figure 6, Figure 33 and Figure 34). Stream gradients where bankfull widths were measured were generally near the value of the 1.8 percent average reference reach slope. See Appendix B for detailed field observations.

Additional bankfull width locations were measured within the reference reach during a site visit attended by WSDOT, comanagers, and the design team for the SR 307 crossing 991572 located approximately 700 feet upstream of this crossing (991999) (BFW #7-10 in Table 3 and Figure 6). During this site visit, which was not attended by the 991999 design team, it was decided that these two crossings should use generally the same reference reach. For continuity in the channel design, a bankfull width of 12.4 feet was agreed upon by the attendees as a starting point for both crossings' design cross sections which were adjusted according to different flow values and design needs. Pebble count data collected from the 991999 reference reach were also utilized by the 991572 design team (Figure 6). The shared 12.4-foot bankfull width will be used along with other parameters to inform design elements such as crossing hydraulic opening size, LWM quantity, minimum freeboard height, and bank-to-bank widths for the proposed channel conditions. Meander amplitude from the 991999 design team reference reach was utilized to inform the proposed channel's horizontal alignment.

Bank heights in the reference reach are about 1 to 2 feet high with slopes ranging between 2H:1V to 3H:1V. Undercut banks were observed in several locations upstream of the crossing. Banks and floodplain areas generally consist of silt or finer material. Channel bottom widths ranged from 8 to 10 feet. Width to depth ratios, which are an indicator of channel shape, generally range from 6 to 10 in the reference reach. Cross section geometry within the channel banks in the confined section downstream of the crossing is generally comparable to upstream. Figure 35 presents existing conditions cross sections at bankfull width measurement locations 6 through 10 noted in Table 3.

Based on analyses presented in Sections 2.7.4, 2.7.5, and 7.2, the creek appears to be in Stage 6 (Quasi Equilibrium) or 7 (Laterally Active) of Cluer and Thorne (2014).

Table 3: Bankfull width measurements

BFW number	Width (ft)	Included in design average?	Location measured *(along existing stationing (ft))*	Location measured *(distance from culvert (ft))*	Concurrence notes
1	10.6	No	16+28	283	Collected by design team 12/10/21
2	11.9	No	15+70	225	Collected by design team 12/10/21
3	10.2	No	14+30	85	Collected by design team 12/10/21
4	11.4	No	10+30	231	Collected by design team 12/10/21
5	11.0	No	9+82	279	Collected by design team 12/10/21
6	9.2	No	9+61	300	Collected by design team 12/10/21
7[1]	14	Yes	17+20	370	Collected during concurrence site visit on 02/02/22 upstream of Crossing
8[1]	10	Yes	17+00	350	Collected during concurrence site visit on 02/02/22 upstream of Crossing
9[1]	13.5	Yes	16+70	320	Collected during concurrence site visit on 02/02/22 upstream of Crossing
10[1]	12	Yes	16+20	275	Collected during concurrence site visit on 02/02/22 upstream of Crossing
Design average	12.4				

Notes: See Appendix D for existing alignment stationing.
[1]Co-project reference reach BFW measurements

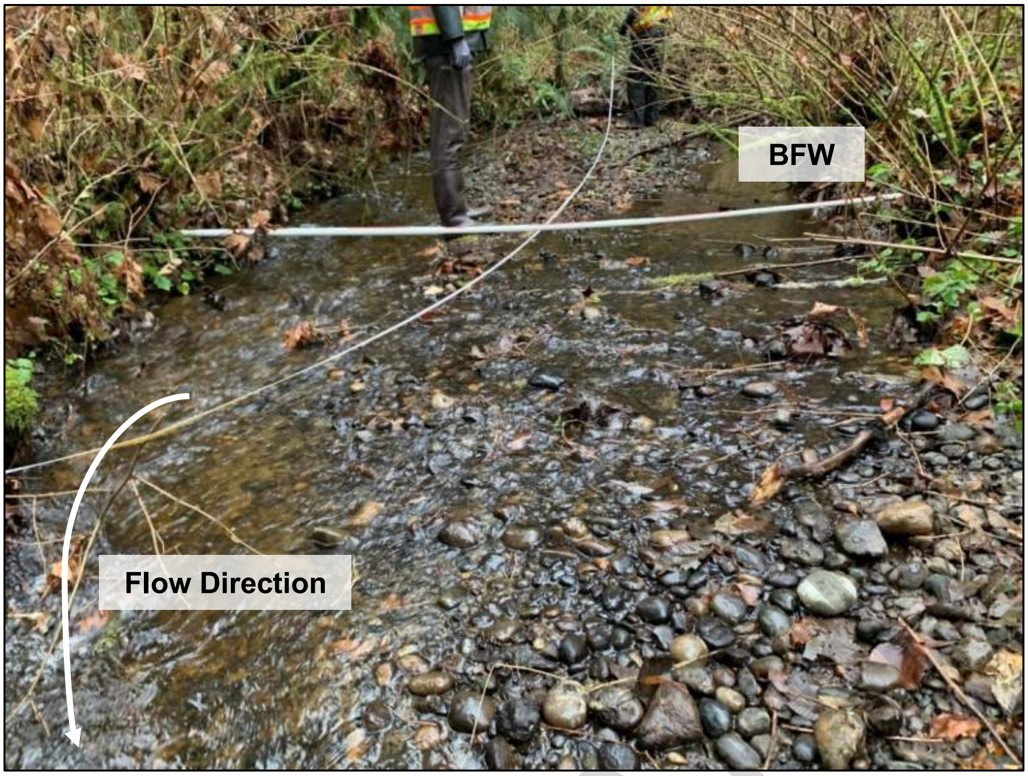

Figure 33: Reference reach near BFW 2 looking upstream

Figure 34: Downstream confined reach BFW 6 with mossy boulders

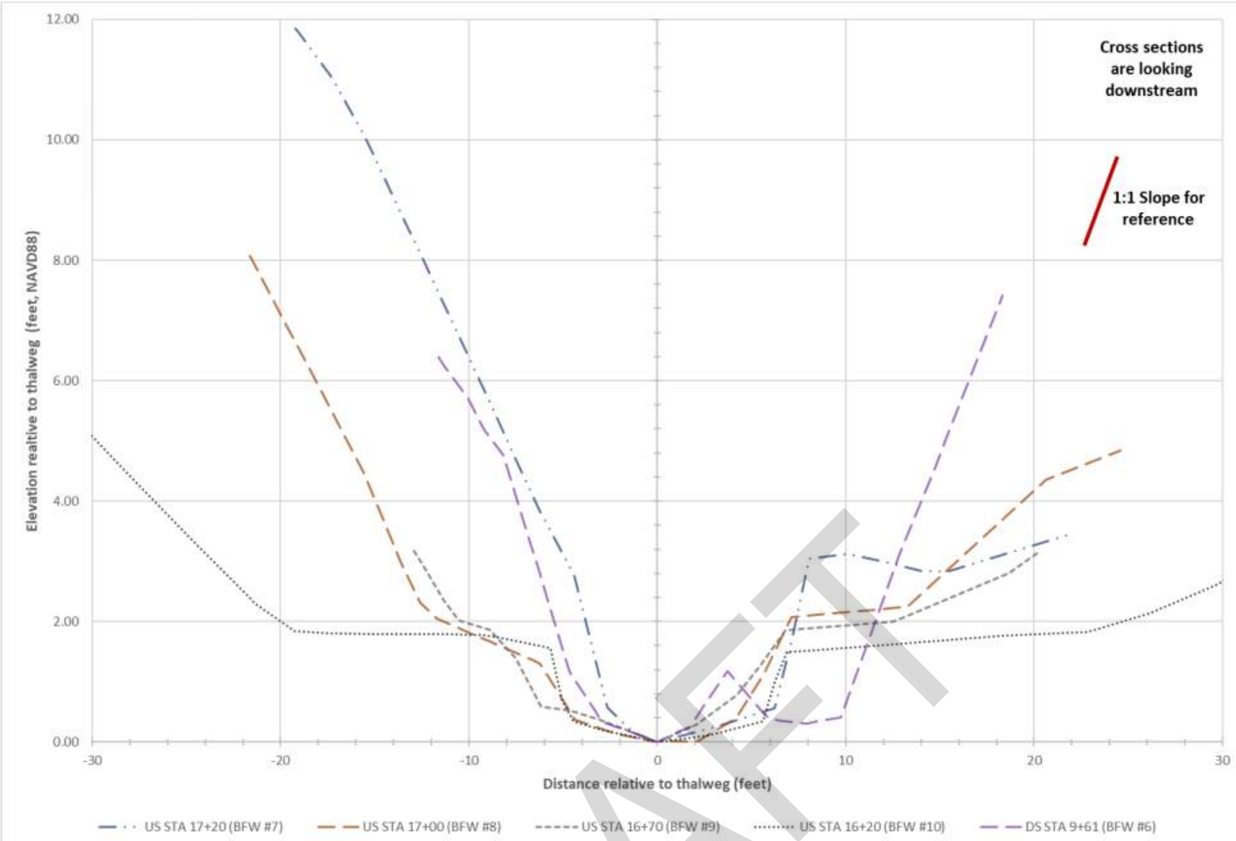

Figure 35: Existing cross-section examples

2.7.2.1 Floodplain Utilization Ratio

The floodplain utilization ratio (FUR) is a comparison of active floodplain width relative to bankfull width. 100-year flow top widths from the existing conditions model were extracted across the existing conditions channel and compared to the concurrence bankfull width of 12.4 feet (Table 4). FUR measurement cross sections were extracted outside of the influence of crossing 991999, within the upstream reference reach, or near bankfull width measurements (Figure 36). Water surface elevations along the existing longitudinal profile in Figure 62 indicate cross sections used for FUR determination are adequately upstream of the 100-year backwater and are not within deposition areas.

UNT to Dogfish Creek flows through an unconfined valley before entering an artificially confined valley once crossing under SR-307. Measurements within the downstream reach and within upstream backwatered areas were included in Table 4; however, these values were not included in the average FUR calculation. The calculated average exceeds 3.0 therefore the design reach is considered unconfined.

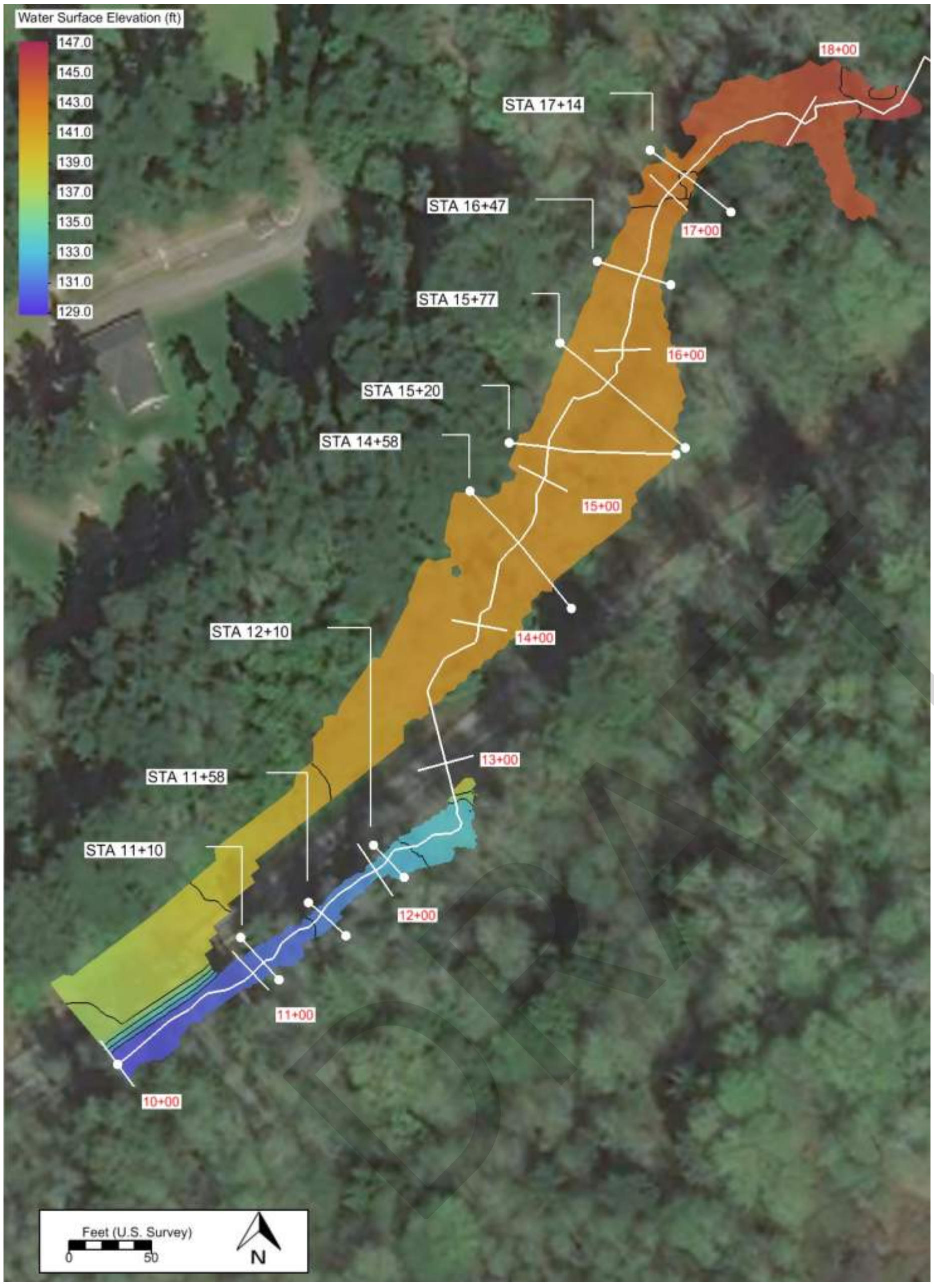

Figure 36: FUR locations

Table 4: FUR determination

Station	FPW (ft)	FUR	Confined/unconfined	Included in average FUR determination
DS 11+10	18.4	1.5	Confined	No
DS 11+58	14.5	1.2	Confined	No
DS 12+10	17.2	1.4	Confined	No
US 14+58 (reference reach)	62.9	5.1	Unconfined	No
US 15+20[1] (reference reach)	95.6	7.7	Unconfined	No
US 15+77[1] (reference reach)	88.7	7.2	Unconfined	Yes
US 16+47 (reference reach)	37.4	3.0	Unconfined	Yes
US 17+14	23.5	1.9	Confined	Yes
Average	**49.9**	**4.0**	**Unconfined**	

Notes: [1]Located near BFW measurement

2.7.3 Sediment

A total of six Wolman pebble counts were collected during the assessment. Three pebble counts were collected upstream and three downstream of the 991999 culvert (Table 5, Figure 37 and Figure 38). Samples were collected at 10 transects along riffles for each pebble count. See Figure 39, Figure 40, and Appendix B for more details and photos. No information was collected to indicate channel sediment armoring characteristics.

Upstream pebble counts, PC1, PC2 and PC3, were at 260, 225 and 130 feet, respectively, upstream of the 991999-crossing inlet. All were collected in the reference reach, and the particle size distributions are presented in Figure 37. Sediment upstream of crossing 991999 was comprised mainly of gravels with smaller portions of sands and small cobbles. No boulders were observed in the upstream reference reach. PC2 and PC3 were located in areas subject to backwatering from the existing 991999 crossing (Section 5.2). These pebble counts were included in the design average as they did not appear noticeably different compared to areas outside backwater extents, for either PC3 (2-year and 100-year backwater) or PC2 (100-year backwater only).

Downstream pebble counts, PC4, PC5 and PC6, were at 70, 180 and 274 feet, respectively, downstream of the 991999-crossing outlet. The sediment downstream of crossing 991999 was slightly larger than upstream, likely due to increased velocity in the narrower downstream channel confined between the highway fill prism and adjacent slopes. Some boulders were observed. Many were angular and presumed to be associated with the SR 307 roadway embankment, but several were somewhat rounded and their origins were difficult to discern. The boulders may be lag deposits from the underlying glacial geology. Most had moss growing on them and are presumed stable at most flows (Figure 34). Boulders were not included in the pebble counts.

Table 5: Sediment properties near the project crossing

Particle size	Pebble Count 1 diameter (in)	Pebble Count 2 diameter (in)	Pebble Count 3 diameter (in)	Pebble Count 4 diameter (in)	Pebble Count 5 diameter (in)	Pebble Count 6 diameter (in)	Average diameter for design (in)
Included in average?	Yes	Yes	Yes	No	No	No	
D_{16}	0.5	0.4	0.4	0.5	0.7	0.4	0.4
D_{50}	1.0	0.8	1.0	1.1	1.5	1.0	0.9
D_{84}	1.8	1.7	1.9	2.2	2.4	2.0	1.8
D_{95}	2.5	2.3	2.5	2.8	3.8	2.9	2.4
D_{100}	5.0	3.5	3.5	5.0	7.1	5.0	4.0

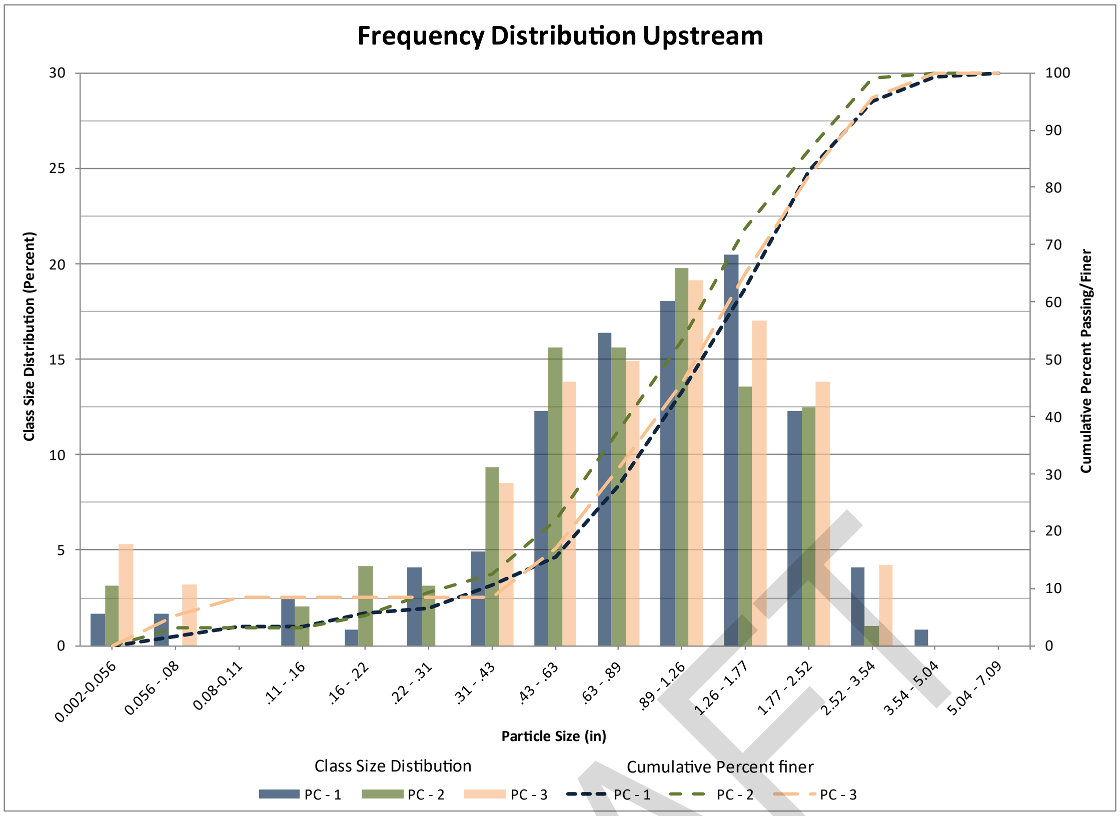

Figure 37: Sediment size distribution in the reference reach

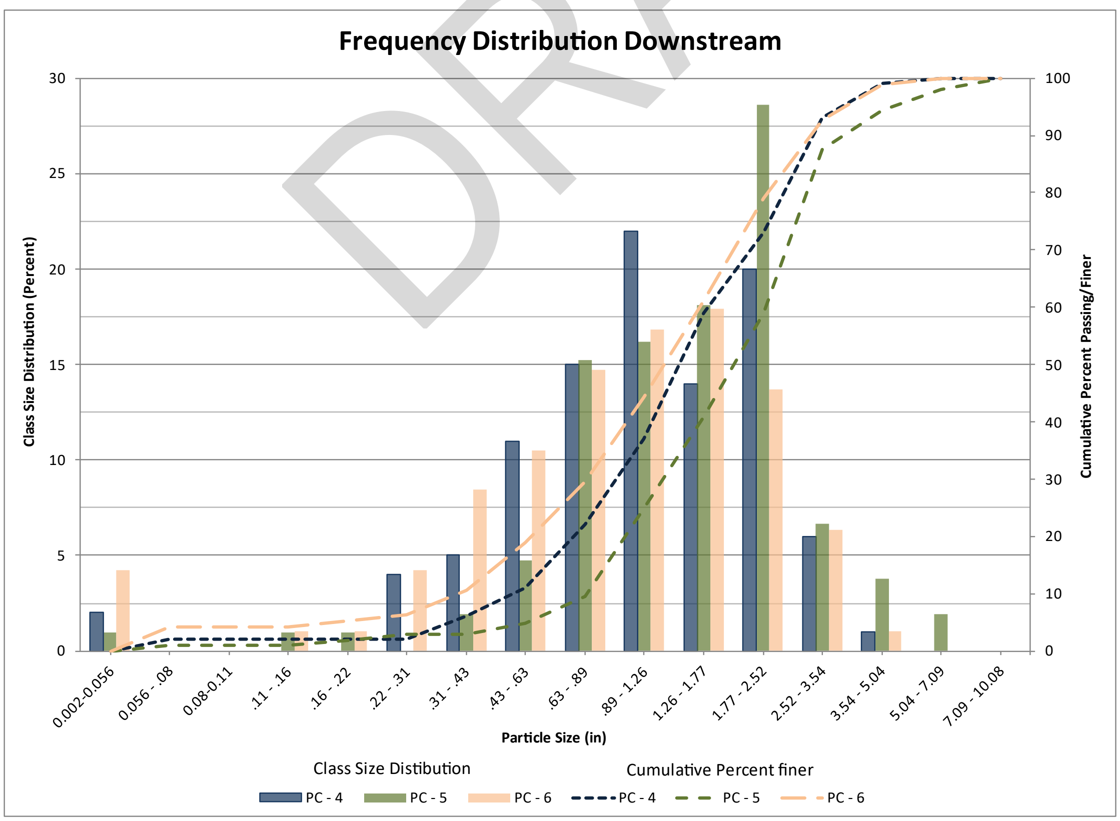

Figure 38: Sediment size distribution downstream of the crossing

Figure 39: Visual of pebble count #3, approximately 100-130 feet upstream of culvert inlet

Figure 40: Visual of pebble count #4, approximately 66-70 feet downstream of culvert outlet

2.7.4 Vertical Channel Stability

Sediment sources are present in the watershed but may not be readily available. Minor hillslope process in the uppermost stream reaches may provide input to the creek but transport to lower reaches is hindered by a wide, flat depositional sink approximately 0.5 miles upstream of the crossing (inset Figure 41). Several small tributaries downstream of the sink may currently be providing the bulk of the sediment to the project location. Erosion hazard and landslide hazard areas are mapped surrounding and adjacent to the reference reach (Kitsap County Department of Community Development GIS Division 2022) that could provide sediment to the channel, though signs of active or recent erosion along adjacent, generally well vegetated hillslopes, were not observed upstream of the crossing. The stream does not appear to be starved of sediment.

Two culverts upstream of the project location likely act as grade control on the main stem: SR 307 Crossing 991572 and Pugh Rd NE (Figure 41). The culvert at Pugh Rd was not observed and stability is unknown. Crossing 991572 will be replaced before or during the life of the new structure for this site, which should allow for transport and distribution of sediment downstream toward crossing 991999. As a result, temporary deposition could occur within the reference reach and downstream through the new crossing.

A significant accumulation of debris has blocked the creek about 350 feet downstream of the culvert (Figure 41 thru Figure 43) creating about a 4- to 5-foot drop in the profile. This blockage appears to have caused local deposition upstream and degradation downstream. The accumulation should be considered temporary and will likely degrade or break loose at some point in the lifetime of the new crossing. Design elements will need to account for the potential degradation of up to 3.0 feet at the crossing if and when this blockage breaks loose (Figure 75). See Section 7.2 for further information about potential degradation.

The creek shows signs of past incision near and upstream of crossing 991572 but there are no signs of active incision within the reference reach or downstream of the 991999 crossing. Nor are there signs of systemic aggradation; deposition is localized and occurs as a result of LWM in the channel. The creek appears near a vertical equilibrium based on the LiDAR data with an equilibrium slope of 1.8 percent that extends for a little over a mile (Figure 41). The proposed gradient of the new channel through the crossing is slightly steeper than the equilibrium slope (Figure 42). The difference between the two slopes shown in Figure 42 represents potential aggradation on the order of about 1 foot or less through the crossing and increasing in the downstream direction.

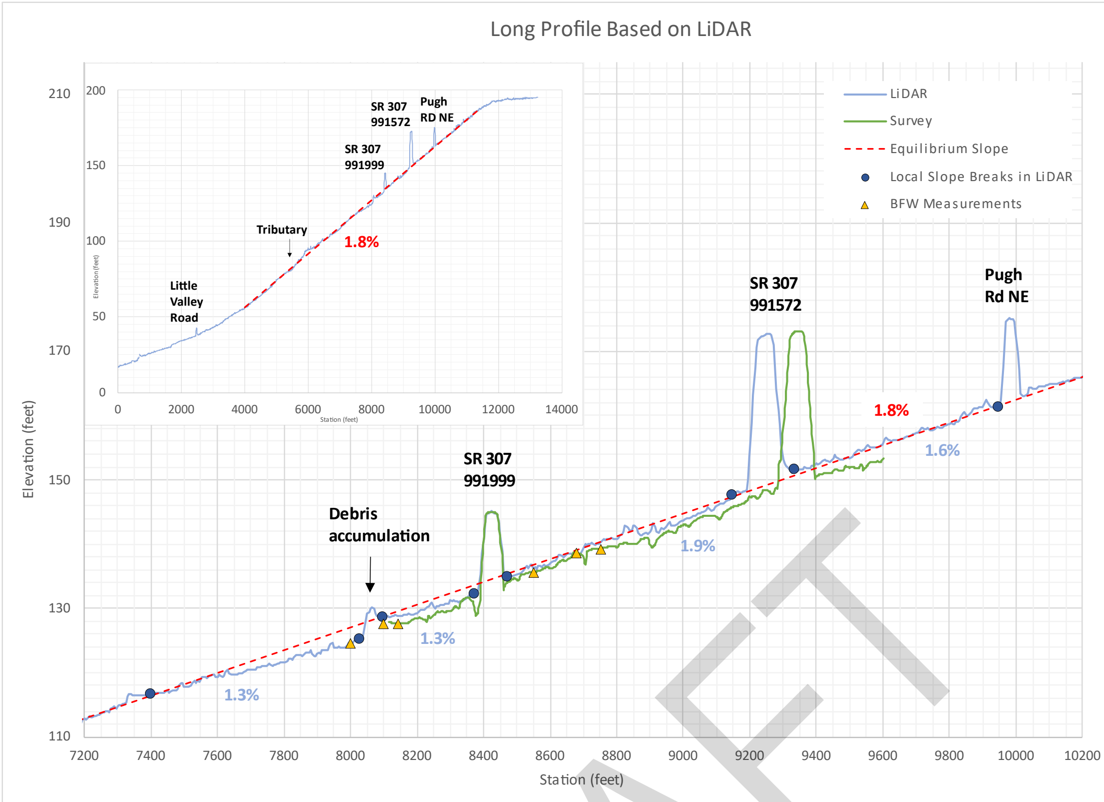

Figure 41: Watershed-scale longitudinal profile

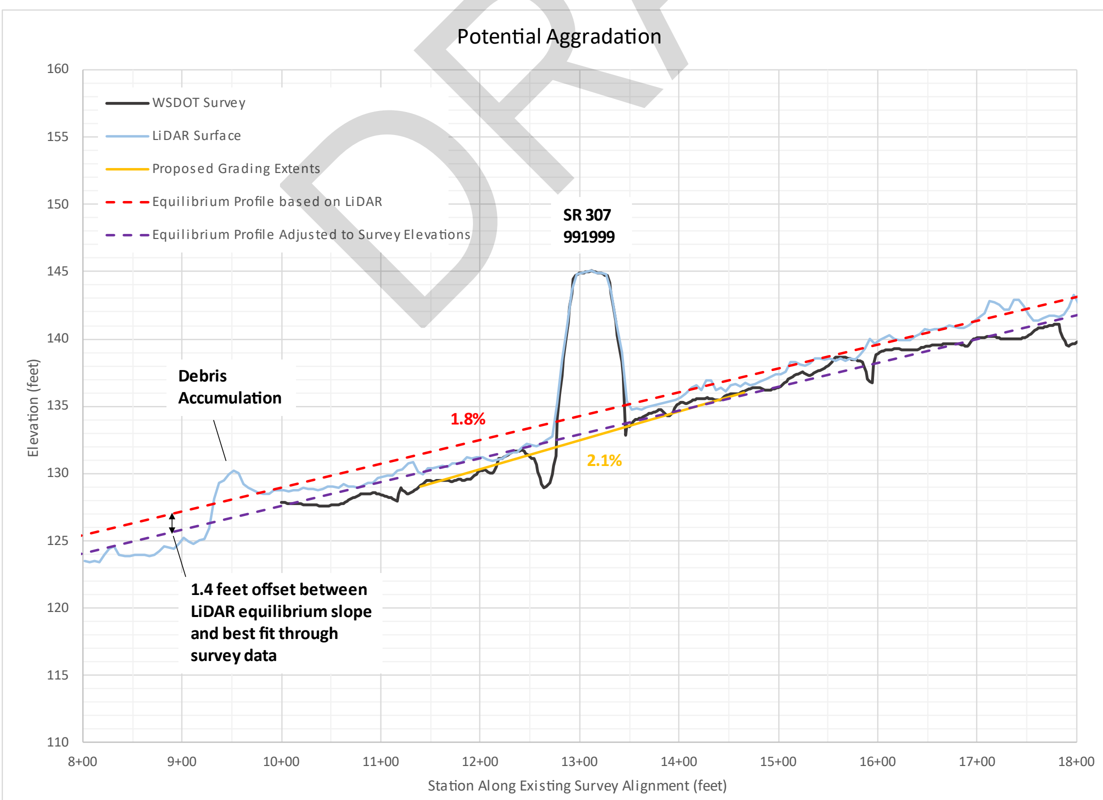

Figure 42: Potential for aggradation

Figure 43: Debris blockage 330 feet downstream of the outlet

2.7.5 Channel Migration

The channel in the reference reach is fairly straight but elsewhere exhibits greater sinuosity. The creek is single thread with a fairly consistent active channel width suggestive of relative lateral stability. However, undercut banks with overhanging vegetation suggest the channel may be trying to widen or move. A wide floodplain within the reference reach allows for channel movement but that diminishes in the downstream direction toward the crossing. According to Rapp and Abbe (2003), a channel migration zone in streams with gradients between 1 and 2 percent is generally considered to encompass the valley bottom.

Local aggradation associated with LWM can force overbank flow generating high flow paths that may one day capture the entire flow of the creek. There is evidence of this in the middle of the reference reach indicating a potential for avulsion. Channel complexity elements (Section 4.3.2) have been included in the stream design within the project grading limits to address this concern.

The valley downstream of the crossing is a naturally narrow portion of the stream corridor relative to up and downstream reaches. The placement of SR 307 within the already narrow corridor completely confines the creek between the road embankment and the valley wall giving the creek no room to move. Neither channel migration nor avulsion are a risk downstream of the crossing.

3 Hydrology and Peak Flow Estimates

Three methods were examined for hydrologic analysis: Gage Basin Transfer Method, Regional Regression Equations, and continuous simulation hydrologic modeling. Per WSDOT Hydraulics Manual, the Gage Basin Transfer Method can only be used for sites where the contributing basin is within 50 percent of the area of the gaged basin (WSDOT 2022a). Further, the WSDOT Hydraulics manual recommends that the gage must have 10 or more years of recorded flow data to be used for the Gage Basin Transfer Method. The closest gage with more than 10 years of flood data for comparison is Dogfish Creek (USGS #120700000). This gage has a coverage area of 3,206 acres versus 1,236 acres delineated for the crossing location. Since the gage has more than double the acreage of the delineated basin, it cannot be used for the basin transfer method as the gaged basin area cannot exceed the delineated basin area by 50 percent. No other nearby gages qualified for analysis as they either had a period of record spanning less than 2 years or had drainage areas that differed from the delineated basin by more than 50 percent.

While the Dogfish Creek gage is not appropriate for use in developing design flows, it does provide a relevant record of low-flow conditions. The gage is currently operated by Kitsap PUD, located near the SR 307/SR 305 intersection, and has a period of record extending from October 1990 to the present (Kitsap County Public Utility District 2022). The lowest flow measured at this gage was 0.48 cfs and occurred in July 2014, and an average 7-day low flow of 1.33 cfs and 30-day low flow of 2.0 cfs were computed from measured data during that same month and year.

The Regional Regression Equations were also investigated for use in developing site hydrology. Per WSDOT Hydraulics Manual, this methodology requires the impervious area relative to the total delineated basin area to be 5 percent or less (WSDOT 2022a). Since the total impervious area equates to 7 percent of total area, the Regional Regression Equations cannot be used for hydrologic analysis of this basin.

MGSFlood was selected for the continuous hydrologic modeling application. This is the continuous-simulation hydrologic model recommended by the WSDOT Hydraulics Manual for Western Washington (WSDOT 2022a). A similar basin was delineated for UNT to Dogfish Creek when analyzing the upstream crossing 991572 hydrology using MGSFlood. Three subbasins were delineated for crossing 991572 to account for the major flow paths. Landcover for each of the subbasin was determined using the National Land Cover Dataset (NLCD 2019) and converted into the MGSFlood land cover classifications of “forest,” “grass,” “pasture,” “impervious,” and “wetland.” Hydrologic soils groups were classified using the USDA Natural Resources Conservation Services (NRCS) Web Soil Survey (Natural Resources Conservation Service 2022) to add subcategorizations of the landcovers of till and outwash.

Crossing 991999 has an additional 8 acres to its contributing basin compared to crossing 991572. GeoEngineers delineated the landcover for the additional area for crossing 991999 and used the NRCS’s Web Soil Survey to determine hydrologic soil groups.

To maintain parity between the two crossings, the three subbasins for crossing 991572 and one additional subbasin for 991999 were input into MGSFlood independently by the 991999 design team. After running the MGSFlood model in 15-minute timesteps, the flows for all four subbasins were extracted then added together to compute the total runoff of the basin for each recurrence interval. Subbasins from crossing 991572 accounted for 1,228 acres while the intervening area between crossings 991572 and 991999 accounted for 8 acres. The computed peak runoff values from the MGSFlood model as shown in Table 6 were used for hydraulic analysis via SRH-2D. Refer to the crossing 991572 Preliminary Hydraulic Design Report for comparison of runoff values from MGSFlood (WSDOT 2022c).

While MGSFlood modeled flows depicted in Table 6 are consistently larger than the comparative methods, they appear in line with field observations. Upstream of the existing 991999 crossing backwater effect, existing conditions modeling using these flows report a 2-year maximum depth of approximately 2 feet (Table 14), depicted in Figure 63. This depth roughly correlates with observations of bank height and signs of scour typically associated with regularly occurring higher flow events. Further, there was a distinct rust line observed at the pipe outlet at just under 2 feet above the invert, with a second distinct coloration difference located approximately 3 feet above the invert (Figure 44). While these observations are highly approximate, they lend credence as a reality-check to these hydrology values as appropriate estimates for the system.

Figure 44. Crossing 991999 outlet with annotated rust and discoloration markings on stadia rod

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for the project site. The design flow for the crossing is 218.8 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow is 61.5 percent, yielding a projected 2080 100-year flow of 353.4 cfs (Table 6).

Table 6: Peak flows for Dogfish Creek at SR 307

Mean recurrence interval (MRI) (years)	Gage Basin Transfer Method (cfs)	USGS Regression Equation (Region 3) (cfs)	MGSFlood (cfs)
2	52.8	35.5	**61.5**
10	93.6	71.1	**126.8**
25	116.7	90.2	**164.9**
50	134.4	104.5	**208.3**
100	153.3	120.2	**218.8**
500	200.6	157.3	**234.1**
Projected 2080 100	247.5	194.1	**353.4**

4 Water Crossing Design

This section describes the water crossing design developed for SR 307 MP 1.34 UNT to Dogfish Creek, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for UNT to Dogfish Creek at SR 307 MP 1.34. As discussed in Section 2.7.1, the upstream and downstream conditions of crossing 991999 are dramatically different. Upstream conditions of crossing 991999 are unconfined, slightly sinuous, and generally follow a pool-riffle geomorphic complex. During higher flow events, the upstream floodplain benches are activated (Appendix H). Downstream of crossing 991999, UNT to Dogfish Creek is confined (between the SR 307 roadway fill and adjacent hillslope), contains anthropogenic rock weirs, and has a highly modified channel geometry. The proposed design removes the existing fish passage barrier and replaces the existing undersized culvert with a structure that promotes natural channel processes that support fish passage. A transitional section of the channel design extends downstream of the proposed crossing to accommodate the differences between the proposed section and the downstream existing conditions.

The width to depth ratio of the proposed cross-section upstream and through the crossing is 8.7 (Figure 45), which fits within the range of ratios from bankfull width measurements taken from the upstream reference reach (6 to 10) (Section 2.7.2). Downstream of the crossing, width to depth ratios generally range from 6 to 22, as widths contract through the confined valley.

As the upstream conditions of the crossing are unconfined (Section 2.7.2.1), both a proposed conditions and a natural conditions hydraulic model were developed. The natural conditions model served as a baseline for comparison of channel velocities within the system. The channel design for both the proposed and natural conditions hydraulic models are discussed in the following sections.

4.1.1 Channel Planform and Shape

The proposed channel planform and cross-sectional shape were informed by the reference reach conditions and professional judgment (Section 2.7.1). The design bank-to-bank width of 12.5 feet is slightly larger than the existing BFW of 12.4 feet. Simulating the unconfined nature of the upstream conditions, the design section is intended to regularly inundate its 6.5-foot, left and right floodplain benches. Matching bank heights that were observed in the reference reach and in order to meet velocity ratios (Section 5.3), a main channel depth of 1.5 feet was designed (Figure 45 and Figure 46). The 2-year flow fully activates both floodplain benches and extends approximately to the back-of-bench transition. At approximately station 12+15, the proposed grading transitions to the existing downstream channel shape to the downstream tie-in location (Appendix D). Due to the encroaching SR 307 road embankment and the adjacent hillslope, the design floodplain benches were removed, and the general proposed channel shape was matched to the existing shape.

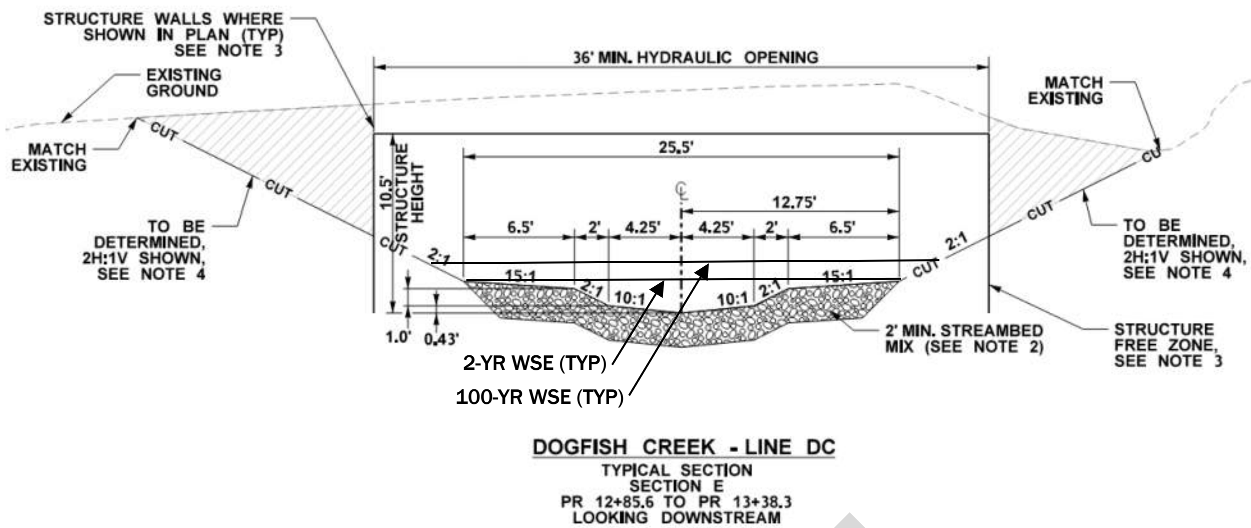

Figure 45: Design cross section

In-stream channel complexity such as large wood, habitat boulders, and meander bars will help to develop variability during all flows. In later stages of the project, a low-flow channel will be added that connects habitat features together so that the project is not a low-flow barrier. The low-flow channel will be installed as directed by the engineer in the field.

The natural conditions channel shape, developed for input to the hydraulic model for use in determining velocity ratios, follows the same main channel alignment as the proposed conditions. The natural conditions channel section was developed using general reference reach geometry and is intended to approximate the reference reach conditions. However, where the cross-sectional shape deviates from the proposed sections, is in the floodplain bench width. Looking to match an average valley bottom width (as if SR 307 was removed entirely), the overall back-of-bench to back-of-bench was set at 70 feet. This is discussed in more detail in Section 5.3 and shown in Figure 67. A natural conditions slope of 1.8 percent was utilized, mimicking the reference reach and general conditions of the valley through the project reach.

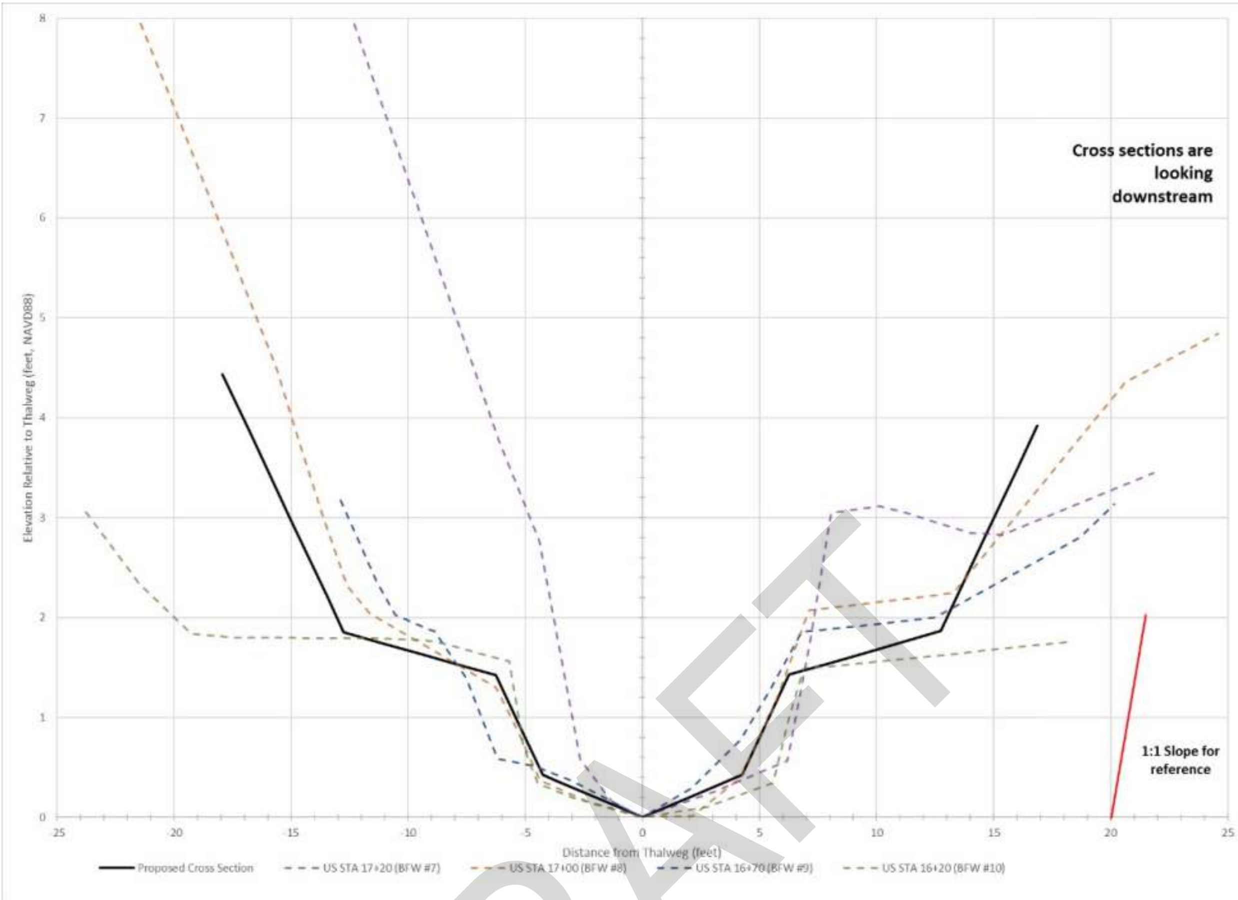

Figure 46: Proposed cross section superimposed with existing survey cross sections (cross sections looking downstream)

4.1.2 Channel Alignment

The proposed channel is generally straight but includes some sinuosity intended to simulate the small curves found in the reference reach (sinuosity = 1.08) (Section 2.7.2). Relative to channel width, the ratio of meander amplitudes ranges from 3.2 to 4.4. The existing crossing includes sharp, near 90-degree turns into the culvert's inlet and immediately downstream from the outlet (Section 2.6). The proposed channel alignment deviates from the existing crossing alignment to avoid sharp bends. The proposed alignment follows the existing downstream alignment for approximately 75 feet to remove the man made rock weirs. Due to the proximity to the road embankment and adjacent hillslope, there was not availability to deviate from the existing alignment.

The proposed channel grading extends approximately 100 feet upstream of crossing 991999's existing culvert inlet and approximately 150 feet downstream of the existing outlet. The total creek reconstruction length along the proposed alignment is 326 feet and crosses SR 307 at a 35-degree skew to normal (Appendix D).

For the natural conditions hydraulic model, a new alignment was developed connecting the upstream and downstream reaches as if SR 307 did not exist. The natural condition's alignment contains minor bends, like what is observed in the reference reach.

4.1.3 Channel Gradient

The proposed channel design for crossing 991999 consists of 326 feet of channel regrade at a slope of 2.1 percent (Appendix D). The proposed slope is within the recommended 25 percent (slope ratios of 0.75 to 1.25) of the upstream reference reach gradient of 1.8 percent (WSDOT 2022a). The slope ratio between the upstream reference reach slope and the proposed design slope is 1.17. Downstream of the existing culvert, the average existing gradient is shallower at 1.3 percent. The existing downstream debris blockage in the stream may be contributing to the shallower slope. The slope ratio between the downstream reach gradient and the proposed design slope is 1.6, which exceed the recommended 1.25 ratio.

There is a risk of aggradation at the downstream tie-in location as the slope transitions from 2.1 percent to the shallower gradient. This location is approximately 150 feet downstream of the proposed crossing structure outlet and is not anticipated to affect the crossing structure. The potential for aggradation was considered in vertical clearance recommendations (Section 4.2.3). Detailed discussion and analysis of long-term aggradation is discussed in Section 2.7.4 while degradation is discussed in Section 7.2.

For the natural conditions stream grading, a slope of 1.8 percent was chosen to best mimic the reference reach and follow the average slope through the project reach (Figure 41).

4.2 Minimum Hydraulic Opening

The minimum hydraulic opening is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance; for discussion on scour elevations, see Section 7. See Figure 47 for an illustration of the minimum hydraulic opening, hydraulic width, freeboard, and maintenance clearance terminology.

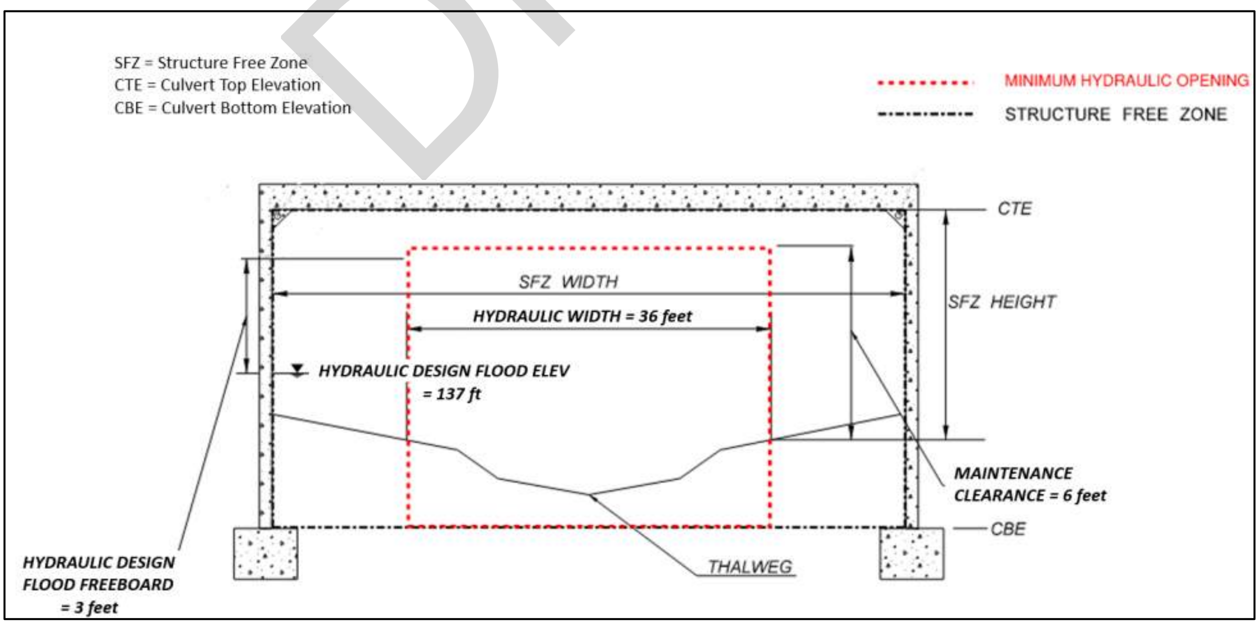

Figure 47: Minimum hydraulic opening illustration

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022a). Using the guidance in these two documents, the Unconfined Bridge methodology was deemed most appropriate due to the unconfined nature of the upstream conditions. The floodplain utilization ratio (FUR) was used to determine channel confinement (Section 2.7.2.1). The average FUR of the modeled reach was found to be greater than 3.0, indicating confined conditions.

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of all WSDOT crossings is Equation 3.2 of the WCDG, with the result rounded up to the nearest whole foot (Barnard, et al. 2013). For this crossing, a minimum hydraulic width of 17 feet was determined to be the minimum starting point. This is based on the concurrence bankfull width of 12.4 feet discussed in Section 2.7.1.

For an unconfined system, WSDOT guidance requires that main channel average velocity through the proposed structure does not exceed the average main channel velocity immediately upstream of the structure, if roadways and infrastructure were to be removed, by more than 10 percent (a ratio of 1.1) (WSDOT 2022a). Average main channel velocities from the proposed-conditions hydraulic model were compared to results from the natural conditions model (Section 4.2.1 and Section 5.3).

Table 7 reports the comparison of velocities in the form of a ratio between proposed and natural conditions velocity (proposed divided by natural) for the 100-year event. Average main channel velocities were compared at the reference reach and at cross sections directly upstream of the crossing, directly downstream of the crossing, and through the proposed crossing. Relative to natural conditions, a 36-foot minimum hydraulic opening does not exceed a velocity ratio more than 0.8.

Table 7: Velocity ratio comparison for 36-foot structure (Proposed v. Natural)

Location	100-year velocity ratio (Proposed/Natural)	Projected 2080 100-year velocity ratio (Proposed/Natural)
Reference reach (STA 15+20)	0.7	0.8
Upstream of structure (STA 13+31)	0.6	0.7
Through structure (STA 13+03)	0.6	0.7
Downstream of structure (STA 12+78)	0.6	0.7

After performing hydraulic modeling of existing, natural, and proposed conditions for various flows, and based upon the results of the velocity comparison (Table 7), a minimum hydraulic opening of 36 feet is recommended (Appendix H). Thirty-six feet matches the top width of the projected 2080 100-year peak flow top width through the proposed structure (Figure 71) and results in a factor of safety of 2.9. This will help accommodate proposed stream simulation materials and channel complexity features within the crossing (i.e., meander bars) (Section 4.3.2).

Based on the factors described above, a minimum hydraulic width of 36 feet was determined to be necessary to allow for natural processes to occur under current flow conditions. The projected 2080 100-year flow event was also evaluated. Table 8 summarizes average main channel velocities upstream, downstream, and through the proposed 36-foot MHO for the 100-year and projected 2080 100-year events.

Table 8: Velocity comparison for proposed 36-foot structure

Location	100-year average main channel velocity (ft/s)	Projected 2080 100-year average main channel velocity (ft/s)
DS of Proposed Structure 11+03 (A)	3.2	3.9
DS of Proposed Structure 12+26 (B)	2.9	3.5
DS of Proposed Structure 12+78 (C)	3.1	3.5
Through Proposed Structure 13+03 (D)	3.3	3.8
US of Proposed Structure 13+31 (E)	3.2	3.6
US of Proposed Structure 13+56 (F)	3.5	4.1
US of Proposed Structure 15+20 (G)	3.7	4.2
US Reference Reach 16+33 (H)	5.7	6.7
US of Proposed Structure17+05 (I)	5.3	6.7

No additional size increases were determined to be necessary to accommodate for climate change, as the design is based on projected 2080 100-year event flow top widths and constriction of flow is not observed. For detailed hydraulic results see Section 5.4.

4.2.3 Vertical Clearance

The vertical clearance under a structure consists of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 9.

The WSDOT *Hydraulics Manual* requires 3 feet of freeboard for all structures greater than 20 feet and on all bridge structures unless otherwise approved by HQ Hydraulics (WSDOT 2022a). Therefore, the minimum required freeboard at the project location, based on bankfull width, is 3 feet above the 100-year water surface elevation (WSE) (Barnard, et al. 2013).

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE. The WSE is projected to increase by approximately 1 foot for the 2080 projected 100-year flow rate. The minimum required freeboard at this site will be applied above the projected 2080 100-year WSE to accommodate climate resilience.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or LWM. The channel complexity features in Section 4.3.2 do not include elements of significant size and will not need to be maintained with machinery. If it is practicable to do so, a minimum maintenance clearance of 6 feet is recommended for maintenance and monitoring purposes but is not a hydraulic requirement. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width

All inputs and recommendations displayed in Table 9 result in a required minimum low chord of 7.6 feet and 7.2 feet above the channel thalweg at the downstream face and upstream face of the proposed structure, respectively.

Table 9: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	12+78	13+31
Thalweg elevation (ft)	132.0	133.2
Highest streambed ground elevation within hydraulic width (ft)	132.9	135.0
100-year WSE (ft)	135.6	136.5
2080 100-year WSE (ft)	136.6	137.3
Required freeboard (ft)	3.0	3.0
Recommended maintenance clearance (ft)	6.0	6.0
Required minimum low chord, 100-year WSE + freeboard (ft)	138.6	139.5
Required minimum low chord, 2080 100-year WSE + freeboard (ft)	139.6	140.3
Recommended minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	138.9	141.0
Required minimum low chord (ft)	**139.6**	**140.3**

4.2.3.1 Past Maintenance Records

WSDOT Area 2 Maintenance was contacted to determine whether there are ongoing maintenance problems at the existing structure because of LWM or sediment blocking the inlet. The maintenance representative indicated that there was no record of LWM blockage and/or removal or sediment removal at this crossing. However, wood was observed racked near the inlet during site visits (Figure 7).

4.2.3.2 Wood and Sediment Supply

The potential of LWM and sediment transport through the project reach will be more favorable than existing conditions, especially if the upstream crossing 991572 is replaced during a similar timeframe. Surrounding land cover in the project area is relatively under-developed, with upstream riparian areas populated with native trees including Western Red Cedar (*Thuja plicata*) and Big Leaf Maple (*Acer macrophyllum*) (Section 2.6.4). These species range from fair to most desirable durability for stream structures (NRCS 2007). Existing wood currently interacting with the channel appears to include both mobile and immobile pieces, and future pieces of recruited woody material observed growing near the channel may mobilize or stay immobile, depending on size, orientation, and other factors (Section 2.6).

Pending the replacement of upstream crossing 991572, supply of sediment to the project reach will increase. Proposed LWM structures within the proposed grading limits will promote sediment retention.

An existing debris blockage approximately 350 feet downstream of the culvert has created a 4- to 5-foot drop in the longitudinal profile, influencing degradation downstream and deposition upstream (Figure 75). The failure or removal of the blockage may result in up to 3.0 feet of degradation near the upstream face of the proposed crossing structure. At the downstream tie-in location, localized aggradation may occur due to the transition from the proposed 2.1 percent slope to the shallower downstream slope; however, this aggradation is not anticipated to affect the proposed crossing structure. For more detailed discussion of long-term degradation of the channel bed, refer to Section 7.2.

The recommended maintenance clearance of 6 feet and a minimum hydraulic opening of 36 feet is expected to be large enough to transport wood and permit any maintenance activities that may be necessary in the future.

4.2.4 Hydraulic Length

A minimum hydraulic width of 36 feet is recommended. There is no length recommendation because a bridge structure is being proposed.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve SR 307 through this corridor.

4.2.6 Structure Type

No structure type has been recommended by WSDOT HQ Hydraulics. The layout and structure type will be determined at later project phases.

4.3 Streambed Design

This section describes the streambed design developed for Dogfish Creek at SR 307 MP 1.34.

4.3.1 Bed Material

The WSDOT Hydraulics Manual recommends two methodologies for sediment sizing. The Modified Critical Shear Stress method is recommended for slopes under 4 percent while the Unit-Discharge Bed Design is recommended for slopes greater than 4 percent (WSDOT 2022a). From the long profile based on LiDAR (Figure 41), the average slope throughout UNT to Dogfish Creek ranged from 1.8 percent to 2 percent (see Section 2.7.1). Since the average slope is less than 4 percent for the entire designed channel, the Modified Critical Shear Stress was selected for sediment sizing.

The WSDOT Hydraulics Manual notes that the design D_{50} for the proposed gradation needs to be within 20 percent of the reference reach unless constraints prevent this design (WSDOT 2022a). Crossing 991999's proposed D_{50} is within 20 percent from the existing upstream reference reach's D_{50}. The proposed gradation consists of 25 percent 4-inch Cobbles and 75 percent Streambed Sediment per WSDOT Standard Specifications 9-03.11(2) and 9-03.11(1), respectively (Appendix C). This proposed gradation will be mobile at 2-year and higher flows, resulting in potential risk of degradation as the project reach will require adequate sediment supply to avoid degradation. Potential constraints to sediment supply exist upstream from crossing 991999 at crossings 991572 and 930880 as both consist of manmade culverts.

Meander bars are proposed within the crossing structure (Appendix D). Meander bars include two separate streambed material mix designs consisting of a meander bar head gradation and meander bar tail gradation (WSDOT 2022b). The Shield's Critical Shear methodology was used to analyze resistance to shear stresses for both the head and tail components of the meander bar. Per WSDOT meander bar guidance, the head of the meander bar structure shall consist of large rocks designed to be stable at the 100-year flow event (WSDOT 2022b). A 100 percent 12-inch to 18-inch boulders mix design per WSDOT Standard Specification 9-03.11(3) was proposed for the meander bar head structure. The D_{84} and D_{50} remain stable at all annual flows including the 2080 100-year flow per Shield's Critical Shear analysis. Meander bar guidance also states that the stability analysis for the meander bar head shall include flow overtopping rock features (WSDOT 2022b). In the WDFW Stream Habitat Guidelines, it shows Ishbash's equation and Costa's equation to analyze minimum diameter of boulder required to resist design velocity without moving (Cramer 2012). Both equations were used to analyze the minimum diameter of boulder required to resist the 100-year velocity averaged in the main channel under the proposed crossing. After computing the minimum boulder diameter from both equations, the larger diameter was picked to oversize the boulder conservatively. This resulted in a minimum boulder diameter of 1.36 inches to resist the overtopping flows from the proposed 100-year velocity. As the smallest possible boulder size in the proposed meander bar head structure is 12 inches, the proposed meander bar head gradation resists the overtopping flows from the 100-year flow. Refer to Table 10 for summary of the meander bar head gradation and Appendix C for overtopping flow analysis.

The tail of each meander bar will consist of 50 percent or higher by volume material that is equal to or larger than the D_{84} of the proposed streambed gradation to dissipate energy overtopping the boulders (WSDOT 2022b). Further, the tail gradation shall include a large amount of fines to seal the meander bar from subsurface flow. To satisfy these requirements, a meander bar tail gradation of 30 percent Streambed Sediment and 70 percent 10-inch Cobbles per WSDOT Standard Specifications 9-03.11(1) and 9-03.11(2), respectively, was proposed. Per Appendix C and Table 10, the meander bar tail D_{50} is 2.4 inches which is larger than the proposed streambed sediment D_{84} of 2.3 inches, thus satisfying the guidance. Thirty percent Streambed Sediment was added to include enough fines in the meander bar structure to seal it from subsurface flow. It is recommended that additional fines should be washed in as needed during construction to seal the meander bars. See Figure 48 for positioning of the meander bars and Figure 49 for typical meander bar detail.

Table 10: Comparison of observed and proposed streambed material

Sediment size	Streambed Observed diameter for design (in)	Streambed Proposed diameter (in)	Meander Bar Head (in)	Meander Bar Tail (in)
$\mathbf{D_{16}}$	0.4	0.1	13.0	0.6
$\mathbf{D_{50}}$	0.9	0.9	15.0	2.4
$\mathbf{D_{84}}$	1.8	2.3	17.0	7.5
$\mathbf{D_{95}}$	2.4	3.0	17.7	9.3
$\mathbf{D_{100}}$	4.0	4.0	18.0	10.0

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for UNT to Dogfish Creek at SR 307 MP 1.34.

4.3.2.1 Design Concept

The proposed UNT to Dogfish Creek design includes LWM and meander bars to help develop channel complexity, promote aquatic species passage, and increase stability at the proposed stream gradient transitions. No LWM is proposed through the proposed crossing structure. LWM stability calculations were not performed for this report. However, it is anticipated that LWM would be stable through the 100-year flood event. Anchoring, ballast, and stability should be considered in future design efforts.

The function of the LWM is to enhance habitat in the proposed channel by forming scour pools, providing cover, contributing to flow diversity, and encouraging sediment deposition. WSDOT has provided guidance and analysis tools for LWM quantities consistent with *A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forested Basins of Washington State* (Fox and Bolton 2007).

The large wood proposed for this project exceeds the 75th percentile target for all metrics (Fox and Bolton 2007) (Appendix F). Minimum LWM targets are based on the total creek reconstruction length of 326 feet (Appendix F). The targets are determined by habitat zone and bankfull width class. UNT to Dogfish Creek is in the Western Washington habitat zone (Fox and Bolton 2007) and has a bankfull width of 12.4 feet (Section 2.7.2).

- The key piece density target for Western Washington streams with bankfull widths between 0 and 33 feet is 0.0335 key piece per foot of stream. Based on 326 feet of reconstructed stream length, 11 key pieces are required. For streams with bankfull widths between 0 and 16 feet, key pieces should meet a minimum volume of 1.31 cubic yards, not including the rootwad.
- The total number of LWM pieces targeted for Western Washington streams with bankfull widths between 0 and 20 feet is 0.1159 piece per foot of stream reconstruction. Based on 326 feet of reconstructed stream length, 38 total number of LWM pieces are desired.
- The total wood volume targeted for Western Washington streams with bankfull widths between 0 and 98 feet is 0.3948 cubic yard per foot of stream reconstruction. Based on 326 feet of reconstructed stream length, a total wood volume of 128.8 cubic yards is necessary to meet the 75th percentile volume target.

Table 11: LWM Log Metrics (Fox and Bolton 2007)

	No. of Key Pieces	Total No. of LWM Pieces	Total LWM Volume (yd^3)
Design	40	40	218.2
75% Targets	11	38	128.8

LWM is proposed throughout the entirety of the graded channel reach of UNT to Dogfish Creek. LWM pieces were positioned to interact with one another creating diverse flow paths and habitat for aquatic organisms. Low-flow sinuosity and complexity should be encouraged during installation under the direction of the field engineer. Existing topographic features were considered when selecting locations and types for surface LWM structures. Several of the proposed structures were designed to mimic structures observed during the site assessment (Section 2.6). Specifics of LWM sizes can be seen in Appendix F.

Each key-piece is meant to interact with all flows within UNT to Dogfish Creek. LWM pieces have been strategically placed in varying configurations, locations, and angles. Channel-spanning horizontal pieces are not proposed; pieces depicted in Figure 48 that appear to span bank to bank will be installed at an angle to avoid creating a water surface drop that could develop into a fish passage barrier. The proposed layout's intent is to help develop a pool-riffle morphology, retrain sediment to develop a coarser riffle section in some areas and provide cover in resting pools in other areas (Figure 48). Downstream of the proposed crossing, it is anticipated that LWM pieces will be placed along the SR 307 road embankment and adjacent hillslope, in a more vertical fashion. Additional, smaller pieces of LWM should be considered in future design efforts to supplement LWM key pieces and structures.

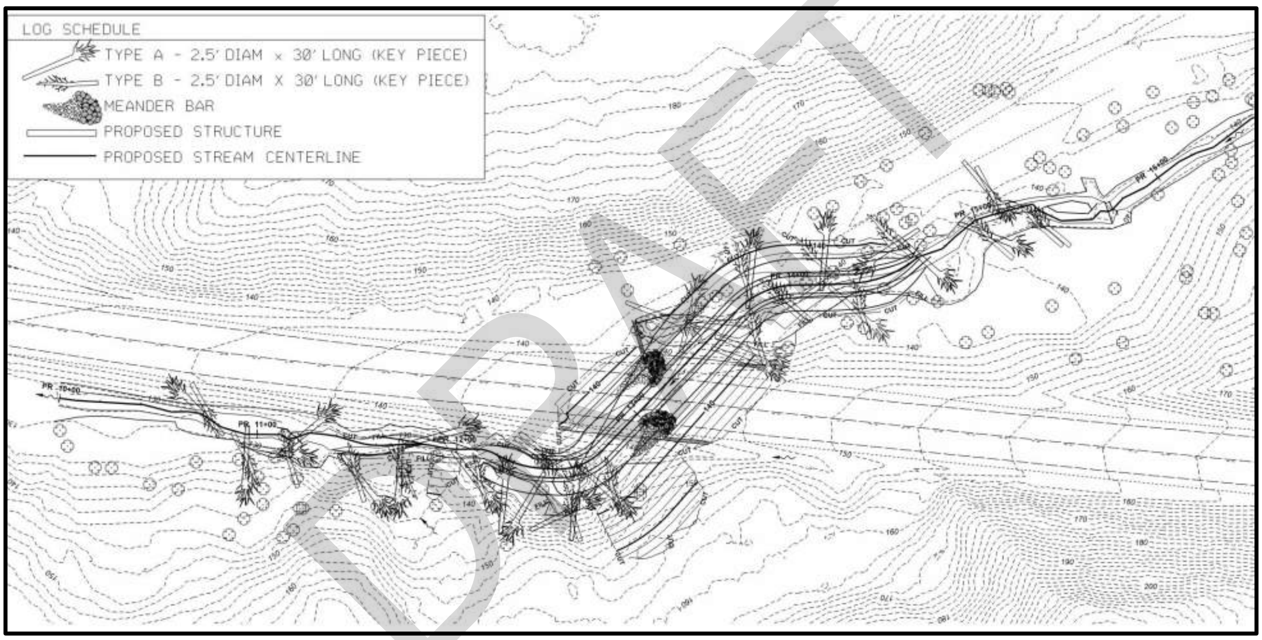

Figure 48: Conceptual layout of habitat complexity features

As LWM is not recommended within the crossing structures, two meander bars are proposed to help develop low-flow channel complexity (Figure 48). The meander bars within the crossing alternate sides of the proposed structure, forcing the low-flow channel to meander back and forth across the stream centerline. The proposed meander bars are also meant to help prevent entrainment along the structure walls. Each bar is meant to protrude into 30 to 50 percent of the active channel width and be built vertically the entire depth of the streambed, including the total scour depth. Each bar should be comprised of streambed material larger than the proposed streambed material for the channel. The head of the structure should include boulders that are stable during the 100-year flow event while the rest of the structure is filled with a mix (Figure 49 and Table 10) (WSDOT 2022b). Mobile woody material is also to be included within the head of the meander bars (WSDOT 2022b). The two meander bars are to be spaced approximately 1 to 2 BFWs apart from each other. Final positioning, material composition, and size of each meander bars should be finalized during final design.

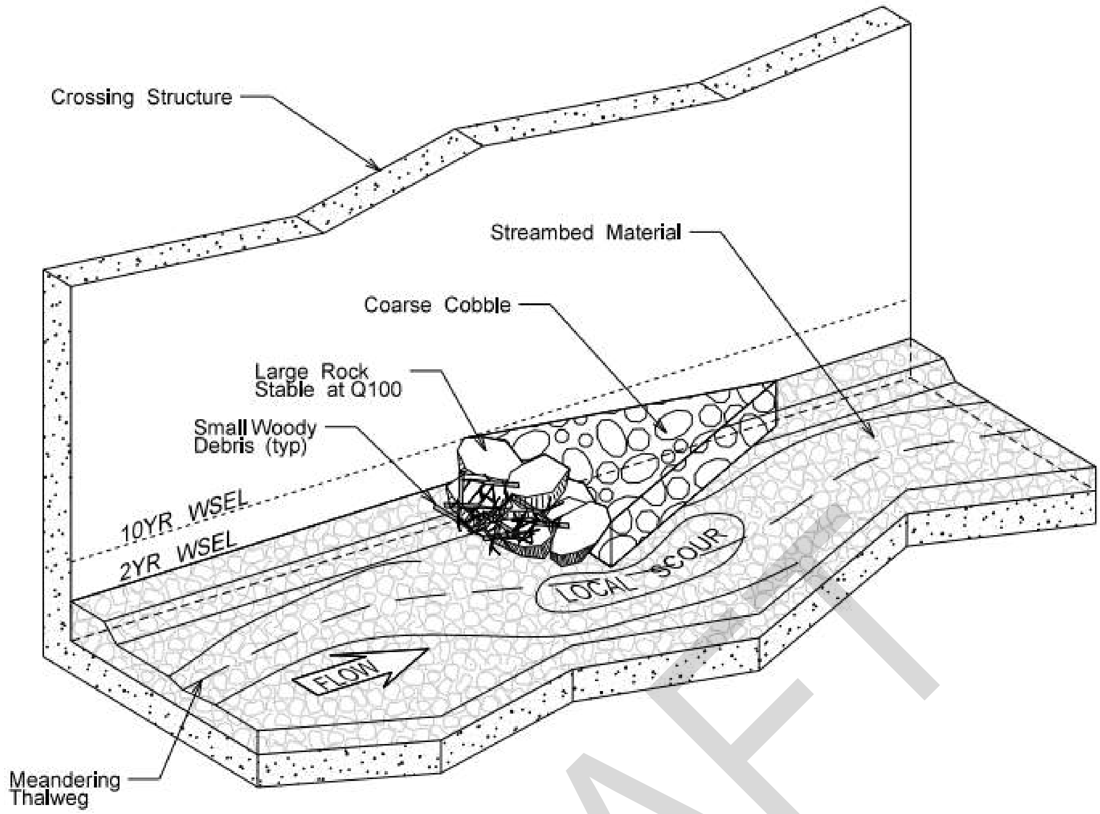

Figure 49. Typical meander bar detail (WSDOT 2022b)

4.3.2.2 Stability Analysis

Large wood stability analysis will be completed at final design.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 307 MP 1.34 Dogfish Creek crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D 3.3.0 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (United States Bureau of Reclamation 2021). Pre- and post-processing for this model was completed using SMS Version 13.1.21 (Aquaveo 2022).

Three scenarios were analyzed for determining stream characteristics for Dogfish Creek with the SRH-2D models: (1) existing conditions with the 4-foot-diameter corrugated steel culvert, (2) natural conditions and (3) proposed conditions with a 36-foot minimum hydraulic opening.

5.1 Model Development

This section describes the development of the models used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office (PEO), which were developed from topographic surveys performed by WSDOT on February 24, 2021. The survey data were supplemented with light detection and ranging (LiDAR) data (OCM Partners 2022). Proposed channel geometry was developed from the proposed grading surface created by Entitlement and Engineering Solutions, Inc (EES). All survey and LiDAR information is referenced against the North American Vertical Datum of 1988 (NAVD88).

5.1.2 Model Extent and Computational Mesh

Existing (Figure 50), natural (Figure 51), and proposed (Figure 52) conditions models were developed under the assumption that the upstream 991572 crossing will be replaced, resulting in unimpeded flows entering the domain. Therefore, upstream domain limits did not include this crossing and start approximately 500 feet upstream of crossing 991999, where the floodplains are narrower. Downstream domain limits were set at the survey extents, approximately 300 feet downstream of crossing 991999. Lateral extents were extended to capture all potential inundated areas within the model domain (> 2x FPW). All model boundaries are assumed to be far enough away from the project site so as not to influence hydraulic model results (FHWA 2019).

The hydraulic model's computational mesh defines important features on a 3D surface. It is composed of triangular and quadrilateral elements whose vertices and nodes define elevations in the mesh. Breaklines were drawn to accurately define channel geometry, SR 307, and domain limits. Elevations at the culvert's inlet and outlet were manually defined to match elevations reported in the WSDOT survey, as recommended by FHWA's 2-D Modeling Guidelines (FHWA 2019).

The computational mesh covers approximately 310,000 square feet. Element vertices were placed approximately every 2 feet along the modeled channel and at every 15 feet at the edge of the model extents. The channel bed, banks, and thalweg were modeled using quadrilateral elements with long axes aligned with the direction of flow whenever possible to optimize computational time. Whenever not possible, due to rapid and irregular change in channel morphology, triangular elements were used to represent underlying terrain. Roadways were modeled using quadrilateral elements and all other terrain elements were modeled using triangular elements. The existing, natural, and proposed conditions mesh contain 24,178 elements (2,503 quadrilateral and 21,675 triangular), 15,441 elements (3,648 quadrilateral and 11,793 triangular), and 21,642 elements (3,087 quadrilateral and 18,080 triangular), respectively.

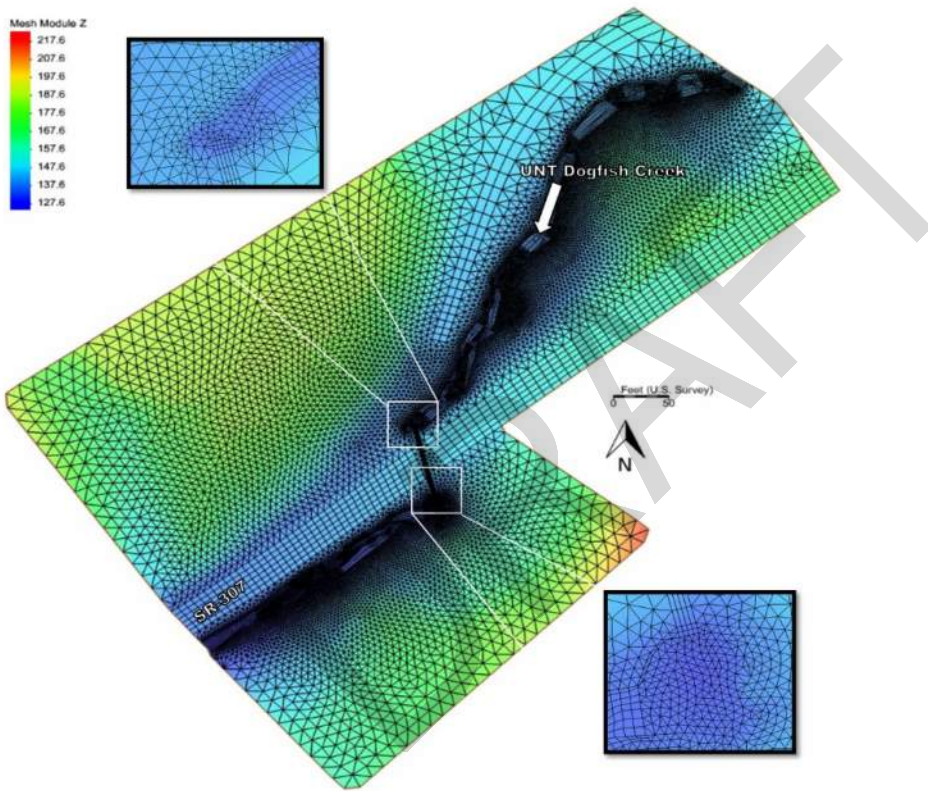

Figure 50: Existing-conditions computational mesh with underlying terrain

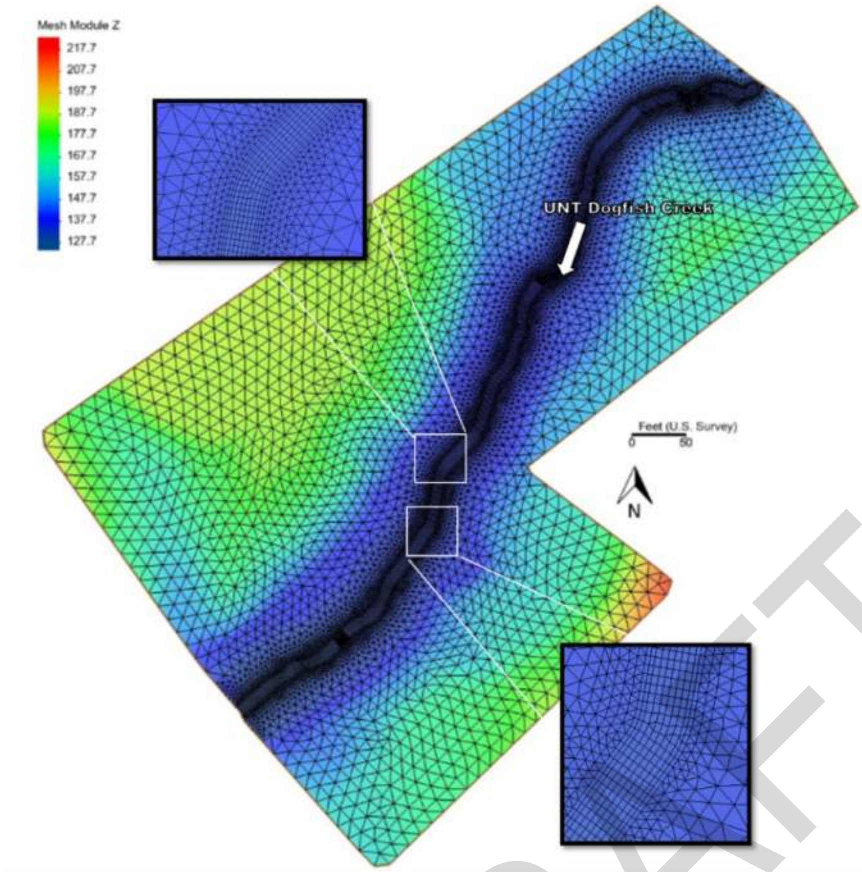

Figure 51: Natural-conditions computational mesh with underlying terrain

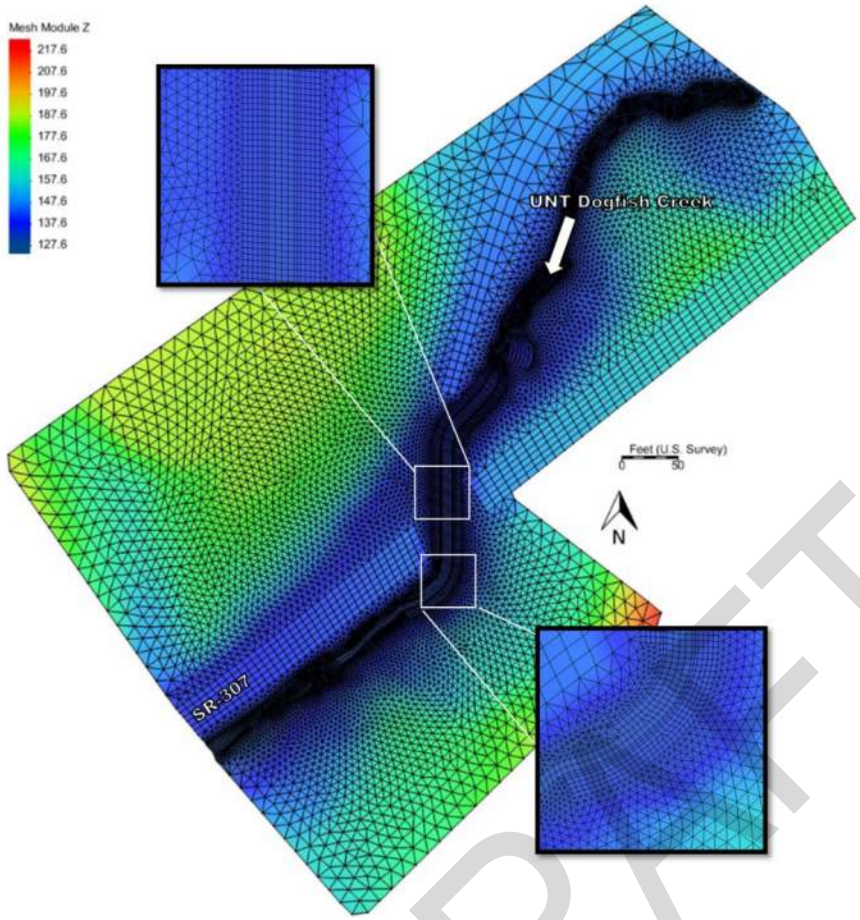

Figure 52: Proposed-conditions computational mesh with underlying terrain

5.1.3 Materials/Roughness

Hydraulic roughness within each model simulation is defined by Manning's n values (Table 12). Material coverages, which define the spatial distribution of roughness values, were delineated for the existing (Figure 53), natural (Figure 54), and proposed (Figure 55) models. They were developed using aerial photography, WSDOT's existing conditions survey base map, the 2019 NLCD, and information gathered during site assessments (Appendix B).

Main channel roughness values for existing, natural, and proposed conditions were approximated using a spreadsheet produced by the U.S. Forest Service (S. Yochum 2018). This tool compares tabular, photographic, and quantitative values to estimate an average composite roughness value. Refer to Appendix E for calculation details. LWM located in existing and proposed conditions are represented by an increased composite channel roughness (Addy and Wilkenson 2019) (S. Yochum 2018). Limitations of this approach are discussed in Section 5.1.6. Roughness values for the floodplain areas and roadways were estimated using field visit photos and tabular guidance from the WSDOT Hydraulic Manual (WSDOT 2022a). Culvert roughness was defined using the FHWA's HY-8 Culvert Hydraulic Analysis Program (FHWA 2022).

The existing conditions model contains five material types: existing stream channel, floodplain, relic gravel road, smooth asphalt (SR-307), and corrugated steel culvert (Table 12) (Figure 53).

Main channel roughness values were calculated upstream and downstream of crossing 991999 to determine if there was a significant difference in roughness. Similarity in slope, bed material, and obstructions resulted in the same Manning's n value of 0.05. One floodplain material roughness was selected for the model domain due to homogeneity of vegetation.

Under natural conditions, the influence of the relic gravel road to the north and SR-307 are omitted. Therefore, only two material types are represented in its simulation: the natural stream channel and its floodplain area (Table 12) (Figure 54). Roughness for the natural stream channel is assumed to be similar to existing conditions.

The proposed conditions model contains six material types: proposed stream channel, existing stream channel, meander bars, floodplain, relic gravel road, and smooth asphalt (Table 12) (Figure 55). It is assumed that roughness outside of grading and LWM limits is identical to the existing conditions model. Within grading limits, the proposed design includes LWM outside the crossing structure and meander bars within. The hydraulic effect of LWM is represented in the composite in-channel roughness values derived from the U.S. Forest Service spreadsheet tool (S. Yochum 2018) (Appendix E).

Table 12: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's n	Rationale	Sources
Existing Stream Channel	0.05	Low relief stream (~2.0%) with LWM, gravels, and vegetation.	(Arcement and Schneider 1989) (Chow 1959) (S. Yochum 2018) (Yochum, et al. 2014)
Natural Stream Channel	0.05	Assumed to be like existing conditions	(Arcement and Schneider 1989) (Chow 1959) (S. Yochum 2018) (Yochum, et al. 2014)
Proposed Stream Channel	0.10	Addition of LWM	(Arcement and Schneider 1989) (Chow 1959) (S. Yochum 2018) (Yochum, et al. 2014)
Proposed Crossing Overbank	0.10	Predominantly cobble and gravel mix. Assumed equal to proposed stream channel.	(Arcement and Schneider 1989) (Chow 1959) (S. Yochum 2018) (Yochum, et al. 2014)
Meander Bar	0.109	Combination of large boulders and woody debris	(Arcement and Schneider 1989)
Floodplain	0.09	Floodplains well developed with some mature cedar (*Thuja plicata*) and alder (*Alnus rubra*) trees but mainly supported dense salmonberry with some vine maple (*Acer circinatum*) and red elderberry (*Sambucus racemosa*)	(Chow 1959)
Existing Adjacent Roadside Ditch	0.09	Ditchline contains similar vegetation to floodplain	(Chow 1959)
Relic Gravel Road	0.023	FHWA value for overland sheet flow	(FHWA 2013)
Smooth Asphalt	0.011	FHWA value for overland sheet flow	(FHWA 2013)
Corrugated Steel Culvert	0.024	HY-8 provided value	(FHWA 2022)

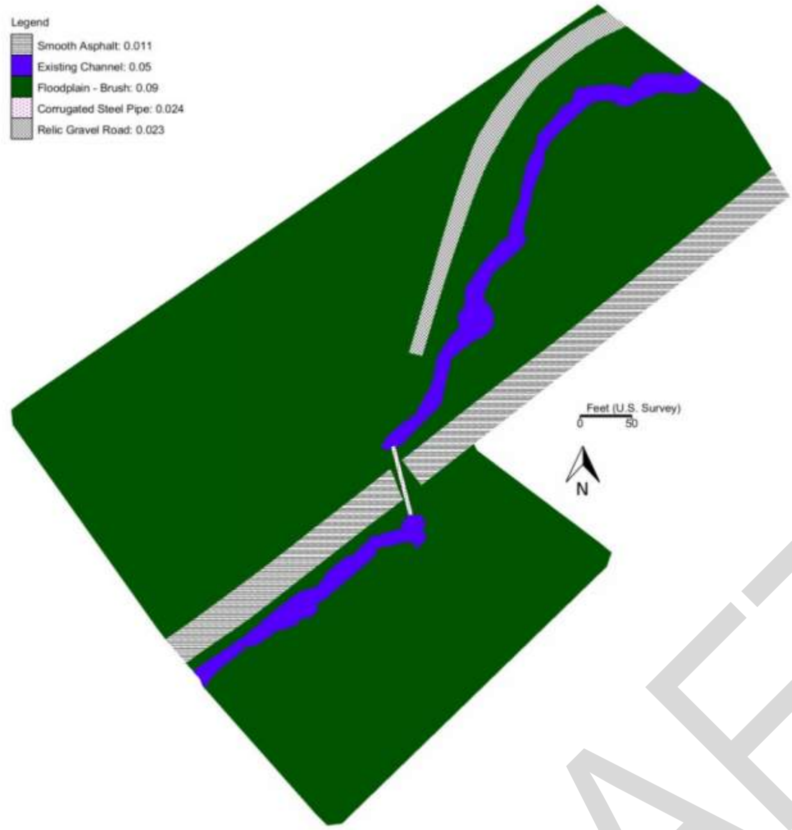

Figure 53: Spatial distribution of existing-conditions roughness values in SRH-2D model

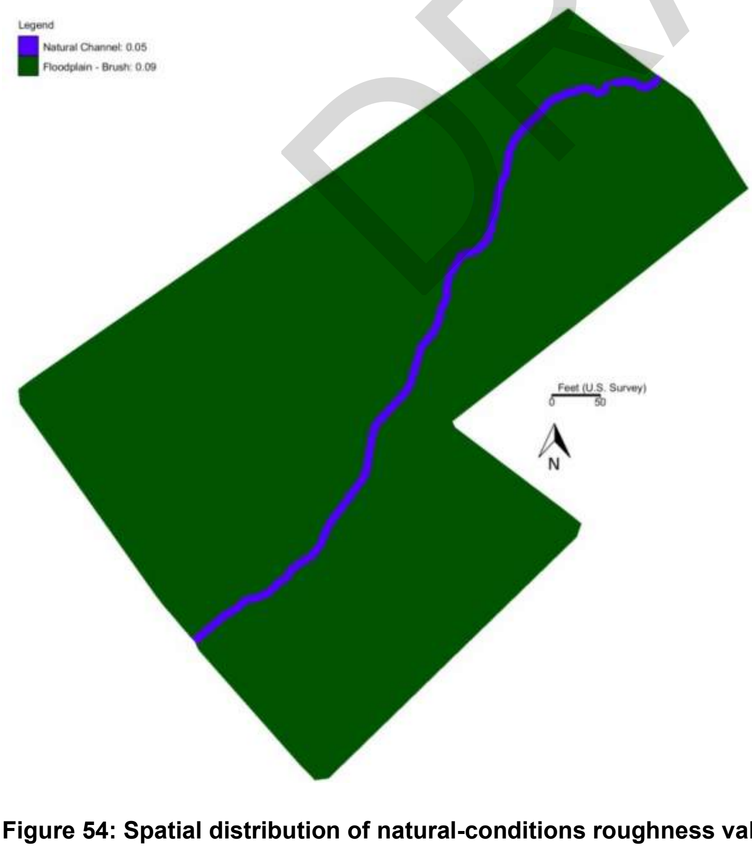

Figure 54: Spatial distribution of natural-conditions roughness values in SRH-2D model

Figure 55: Spatial distribution of proposed-conditions roughness values in SRH-2D model

5.1.4 Boundary Conditions

SRH-2D utilizes user-defined boundary conditions to define how flow enters and exits the model domain. At least one inflow boundary condition at the upstream-most model extent and one water surface elevation boundary condition at the downstream-most model extent is required. Boundary conditions are also used to define culvert inflow and outflow locations. Spatial distributions of the boundary conditions used in the existing, natural, and proposed conditions models are represented in Figure 58, Figure 59, and Figure 60, respectively.

Each model uses the same inflow boundary conditions, based on hydrology discussed in Section 3. Outflow boundary conditions for each model simulation are represented by a constant normal depth water surface elevation (Table 13). An additional outflow boundary was created for the 100-year and 500-year existing conditions to represent flow exiting the domain through an adjacent roadside ditch (Figure 58). It is assumed downstream culverts, west of the model domain, are sufficiently far enough away to not impact model results and are therefore not accounted for in the boundary conditions.

The normal depth water surface elevation for the downstream ditch boundary condition was calculated using its slope of 0.0282 feet/feet and a composite roughness of 0.09. A slope of 0.0127 feet/feet (measured from culvert outlet to the model domain extent) and a composite roughness of 0.07 was used to describe the existing main channel outflow boundary. The natural and proposed conditions used a slope of 0.018 feet/feet and 0.0171 feet/feet, and composite roughness of 0.07 and 0.08, respectively.

HY-8 was used to define the properties of crossing 991999 roadway and culvert in the existing conditions model (Figure 56). This was not needed for the natural or proposed conditions models as the proposed structure is modeled as an open channel, per WSDOT guidelines (WSDOT 2022a).

Table 13: Normal depth water surface elevations for hydraulic modeling

Mean Recurrence Interval (MRI)	Peak Flow (cfs)	Normal Depth Water Surface Elevation (ft)		
		Existing	Natural	Proposed
2	61.5	129.5	129.4	129.5
100	218.8	129.6	130.9	131.1
500	234.1	129.6	131.0	131.2
2080 Predicted 100	353.4	NA	131.7	131.8

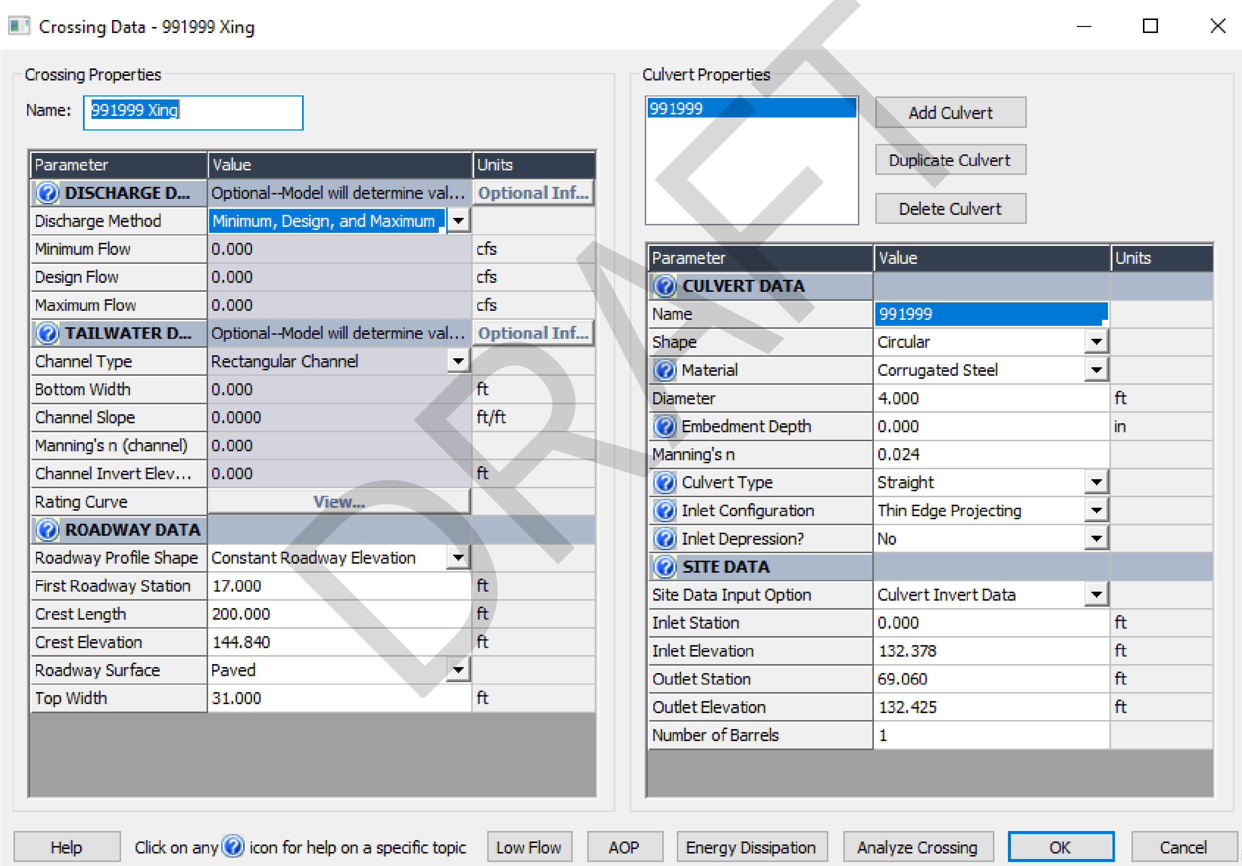

Figure 56: Crossing 991999 HY-8 culvert parameters

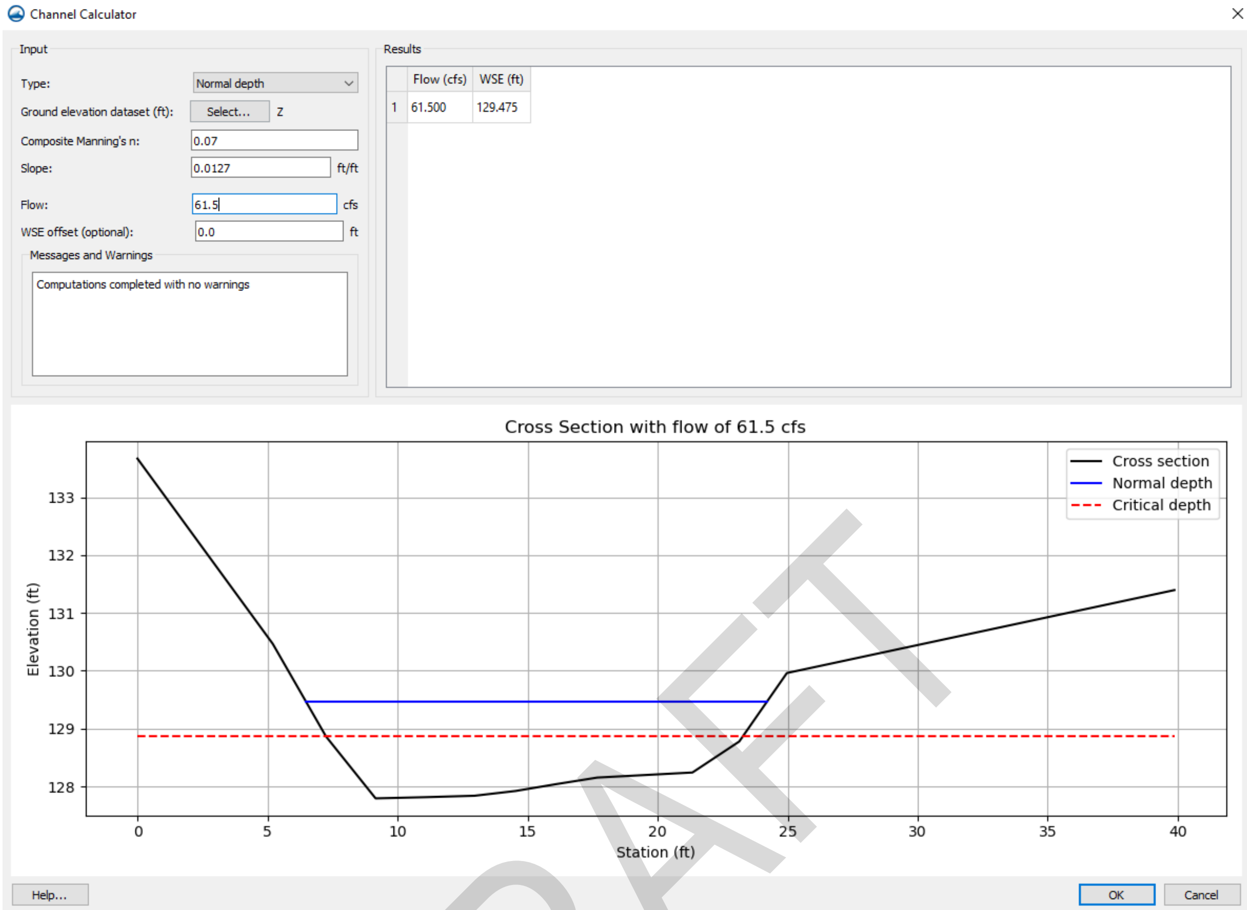

Figure 57: Example downstream outflow boundary condition normal depth channel calculator for existing conditions model under 2-year peak flow of 62 cfs

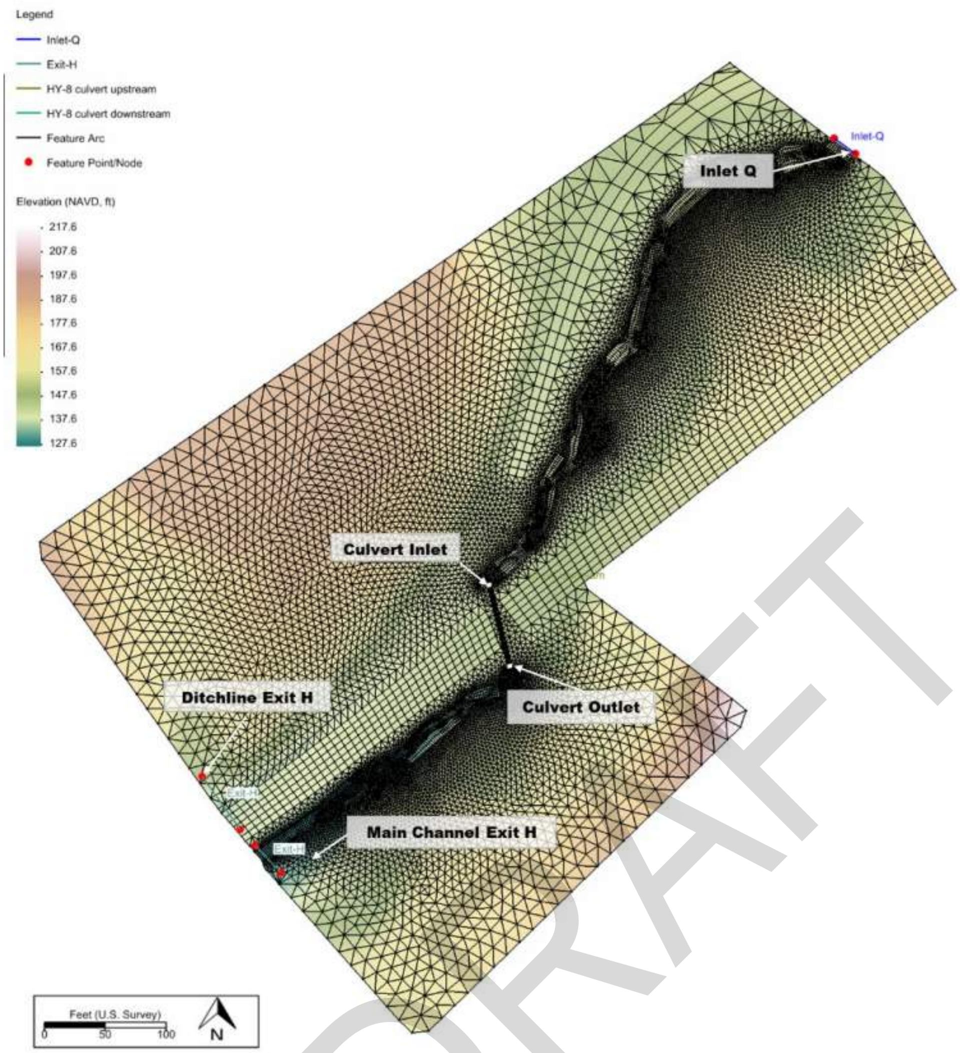

Figure 58: Existing-conditions boundary conditions

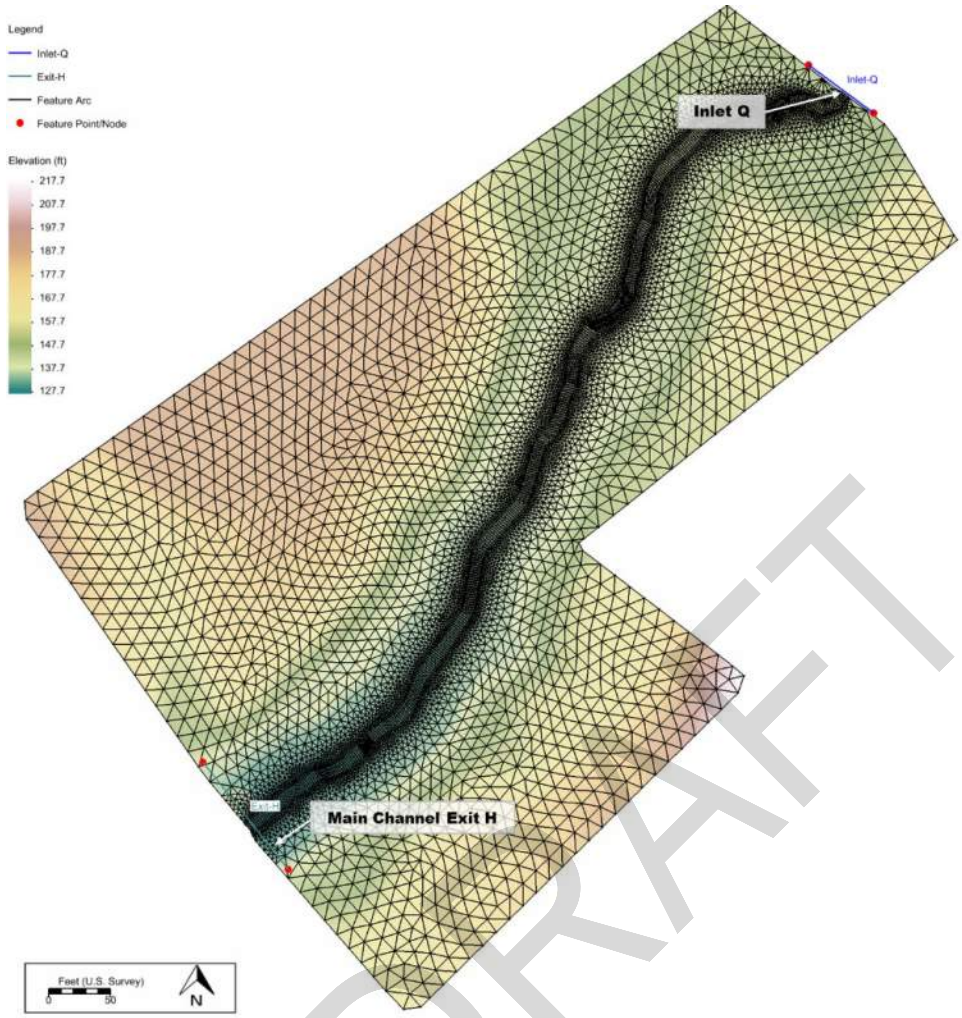

Figure 59: Natural-conditions boundary conditions

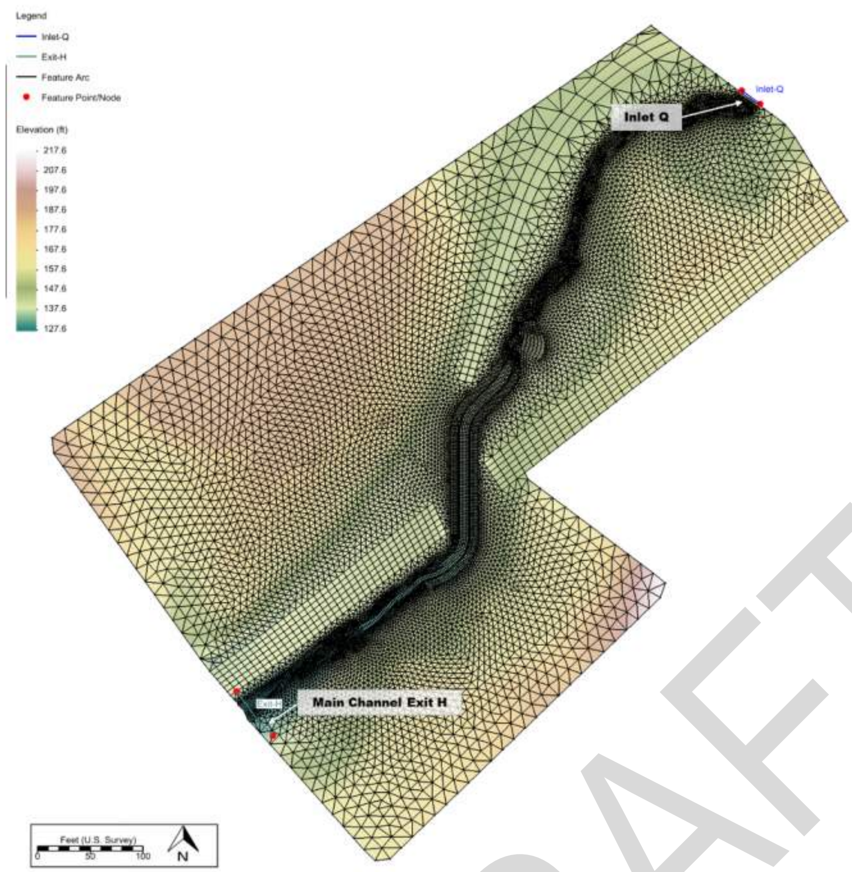

Figure 60: Proposed-conditions boundary conditions

5.1.5 Model Run Controls

All existing, natural, and proposed simulations share the same model run controls and are listed below. Values used in the flow module in the model control of SRH-2D are shown below. All model runs reached a stable steady state result (Appendix I).

Start Time:	0.0
Time Step:	0.2 seconds
End Time:	2.0 hours
Initial Condition:	Dry
Turbulence:	0.7 – Parabolic
Results Output:	0.17 hour

5.1.6 Model Assumptions and Limitations

In all model simulations, the roughness components of large wood and meander bars are modeled by increasing composite channel roughness values. This approach does not account for the fine-scale hydraulic complexity large wood imposes on the stream and assumes adjusting Manning’s n values this way is comparable to modifying the surface to mimic the specific structures.

Stationing between existing, natural, and proposed conditions differ due to altered alignments.

5.2 Existing Conditions

Two-, 100-, and 500-year peak flow events were simulated to evaluate the current conditions of UNT to Dogfish Creek and its crossing under SR-307. The 2-year flow event is used to describe channel forming-like flows, while the 100-year flow is used to define floodplain utilization ratios (Section 2.7.2.1), design LWM placements (Section 4.3.2.1), and estimate vertical clearance needed for a road crossing structure (Section 4.2.3).

Results from the existing conditions model were extracted from eight cross sections along the existing channel alignment: three downstream of Crossing 991999 and five upstream (Figure 61).

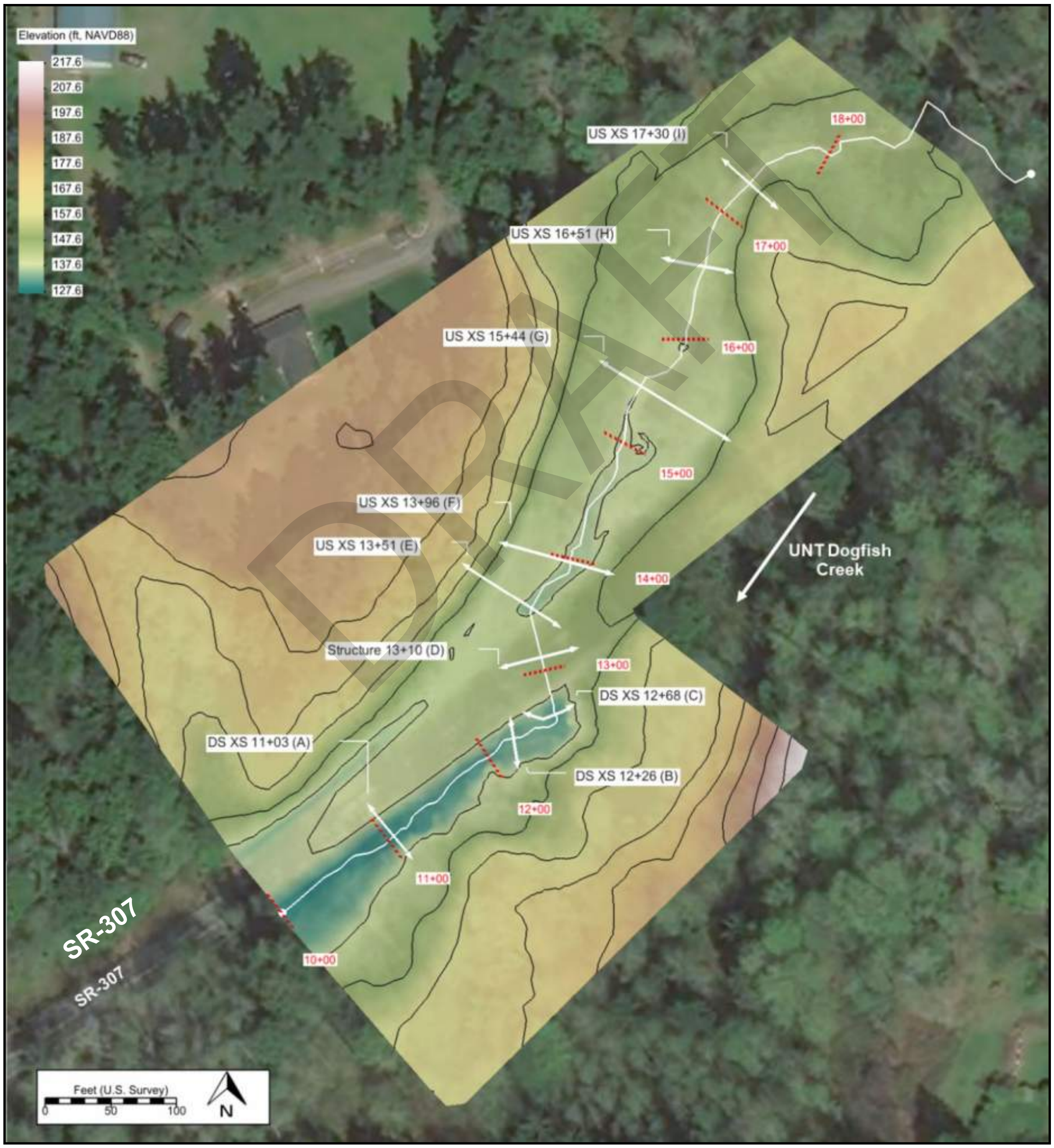

Figure 61: Locations of cross sections used for existing conditions results reporting

Cross Section A is the farthest downstream, outside the zone of influence of crossing 991999 and proposed grading limits. The other downstream cross sections are within the channel grading limits (Cross Section B) and near the existing culvert outlet (Cross Section C). Upstream of the existing culvert, cross sections D and E include the influence of the relic gravel road and sharp turn underneath SR-307. Forty-five feet farther upstream, Cross Section F captures upstream grading limits and the transition into the reference reach. Cross sections G, H, and I are located within the vicinity of the selected reference reach and measured bankfull width measurements (Section 2.7.1). The natural (Figure 65) and proposed (Figure 70) conditions models follow a similar spatial distribution of cross sections; however, stationing is slightly different due to channel realignment.

Topographic break lines from the survey surface were used to define the thalweg and top of banks. Average main channel hydraulic results for existing conditions were extracted using these defined bank lines as lateral bounds (Table 14). This includes average water surface elevation (feet), maximum water depth (feet), average velocity (feet/second), and average shear stress (pound/square foot). Water surface elevations along the existing longitudinal profile and a selected cross section are displayed in Figure 62 and Figure 63. Additional cross-sectional plots and plan view figures of hydraulic results are included in Appendix H.

Table 14: Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft)	DS 10+03 (A)	130.4	130.6	130.6
	DS 12+26 (B)	133.0	133.0	133.0
	DS 12+68 (C)	133.3	133.3	133.3
	Structure 13+10 (D)	NA	NA	NA
	US 13+51 (E)	139.4	141.7	141.8
	US 13+96 (F)	139.5	141.8	141.9
	US 15+44 (G)	139.6	141.9	142.0
	US 16+51 (H)	141.2	142.4	142.5
	US 17+30 (I)	142.1	143.5	143.7
Max depth (ft)	DS 10+03 (A)	2.0	2.2	2.2
	DS 12+26 (B)	1.6	1.7	1.7
	DS 12+68 (C)	4.1	4.1	4.1
	Structure 13+10 (D)	NA	NA	NA
	US 13+51 (E)	5.9	8.2	8.3
	US 13+96 (F)	4.6	6.9	7.0
	US 15+44 (G)	1.8	4.1	4.2
	US 16+51 (H)	1.7	2.8	2.9
	US 17+30 (I)	2.1	3.5	3.6
Average velocity (ft/s)	DS 10+03 (A)	2.5	2.5	2.4
	DS 12+26 (B)	3.7	3.7	3.7
	DS 12+68 (C)	1.8	2.3	2.3
	Structure 13+10 (D)	NA	NA	NA
	US 13+51 (E)	0.8	1.6	1.6
	US 13+96 (F)	0.9	1.6	1.6

Hydraulic parameter	Cross section	2-year	100-year	500-year
	US 15+44 (G)	3.9	2.4	2.4
	US 16+51 (H)	3.6	5.8	5.9
	US 17+30 (I)	3.1	5.6	5.4
Average shear (lb/SF)	DS 10+03 (A)	0.4	0.4	0.4
	DS 12+26 (B)	0.9	0.9	0.9
	DS 12+68 (C)	0.3	0.5	0.5
	Structure 13+10 (D)	NA	NA	NA
	US 13+51 (E)	0.0	0.1	0.1
	US 13+96 (F)	0.0	0.1	0.1
	US 15+44 (G)	1.2	0.3	0.3
	US 16+51 (H)	1.0	1.9	1.9
	US 17+30 (I)	0.8	2.0	2.1

Main channel extents were approximated by inspection of topographic survey breaks.

The existing crossing creates backwater conditions for the 2-, 100-, and 500-year flood events, extending up to STA 15+00 during the 2-year flow and extending up to STA 15+77 during the 100-year and 500-year events (Figure 62, Figure 63, and Table 14). Because 100-year backwater conditions encroach on the selected reference reach, design features such as bed gradation, channel geometry, and floodplain utilization ratios may be impacted. The furthest downstream extents of the reference reach (up to Sta 15+77) are, however, only backwatered during less frequent, extreme events and are therefore impacted less than the area within 2-year backwater extents (between Sta 15+00 and the existing undersized culvert).

Large portions of the 100- and 500-year flows (approximately 151 cfs and 166 cfs, respectively) are conveyed through the roadside ditch northwest of SR-307 and reconnect with UNT to Dogfish Creek through a culvert downstream of the model domain limits. Hydraulic Toolbox was used to compute a maximum flow through a 4-foot-diameter CST pipe to corroborate the quantity of flow traveling through ditch. It was determined that approximately 80 cfs is the maximum expected flow through a culvert of this size under ideal conditions. An additional downstream boundary condition was used to account for the ditch flow in the model (Section 5.1.4). Due to backwatering, maximum flow depths reach 5.9 feet, 8.2 feet, and 8.3 feet behind the existing culvert under the 2-, 100-, and 500-year flood events, respectively (Table 14). Because most of the 100- and 500-year discharges are conveyed through a roadside ditch, rather than the main channel, it is important to note this when comparing hydraulic results between existing and proposed conditions. Downstream velocities and depths, therefore, will inherently appear much larger under proposed conditions because the proposed crossing is designed to convey all flows through the crossing rather than around it.

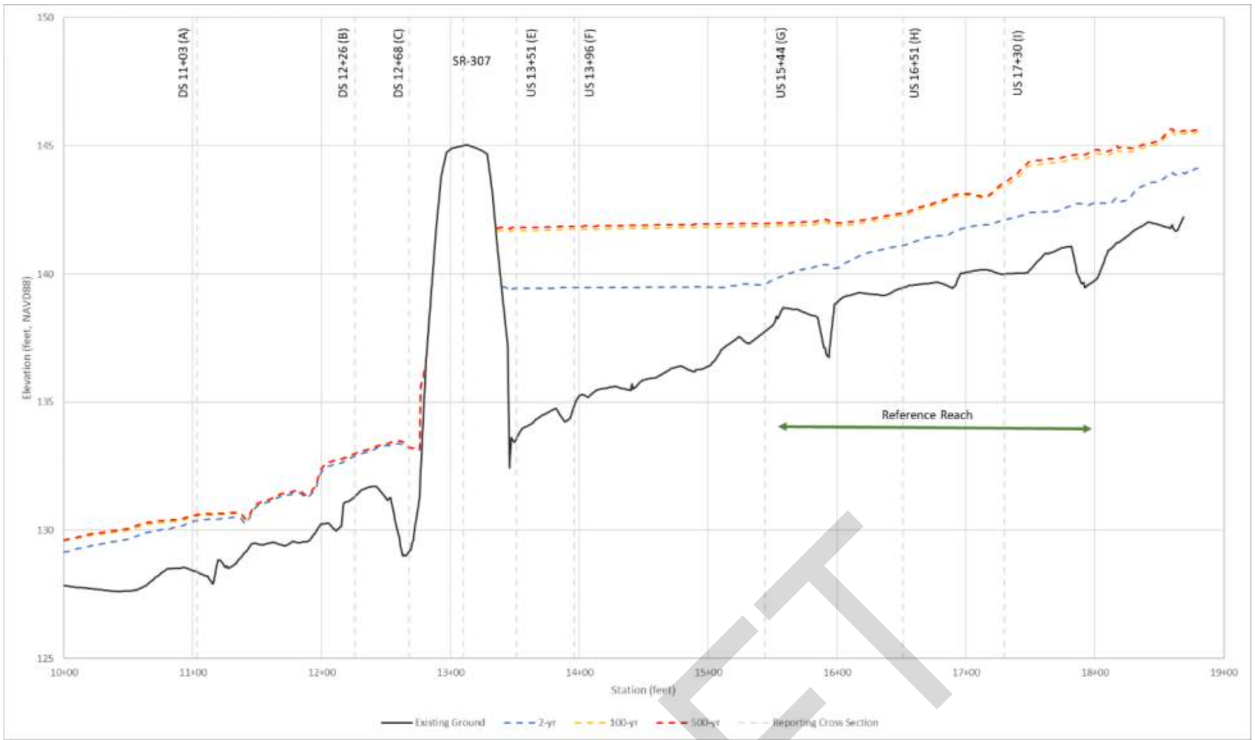

Figure 62: Existing-conditions water surface profiles

In areas where flow is not affected by backwatering (Cross Sections A, B, C, H, and I for the 2-year events and cross sections A, B, and C for the 100- and 500-year events), depths are shallow, with average maximum depths of 2.3 feet, 2.6 feet, and 2.7 feet, respectively. Flow is generally fully contained with bank limits during the 2-year flood event, except between stations 15+00 and 16+00, where topography is lower at the meander bend, influencing floodplain interaction. Flows spills out onto the floodplain under the 100- and 500-year modeled flows, particularly in the unconfined upstream area. Once UNT to Dogfish Creek crosses SR-307, flow is primarily contained within banks at all modeled flows. In areas where flow is not affected by backwatering, average main channel velocity is 2.9 ft/s, 2.8 ft/s, and 2.8 ft/s at the 2-, 100-, and 500-year events, respectively. Velocities are highest at the furthest upstream extents of the model due to a sharp bend located near the domain entrance (Table 15).

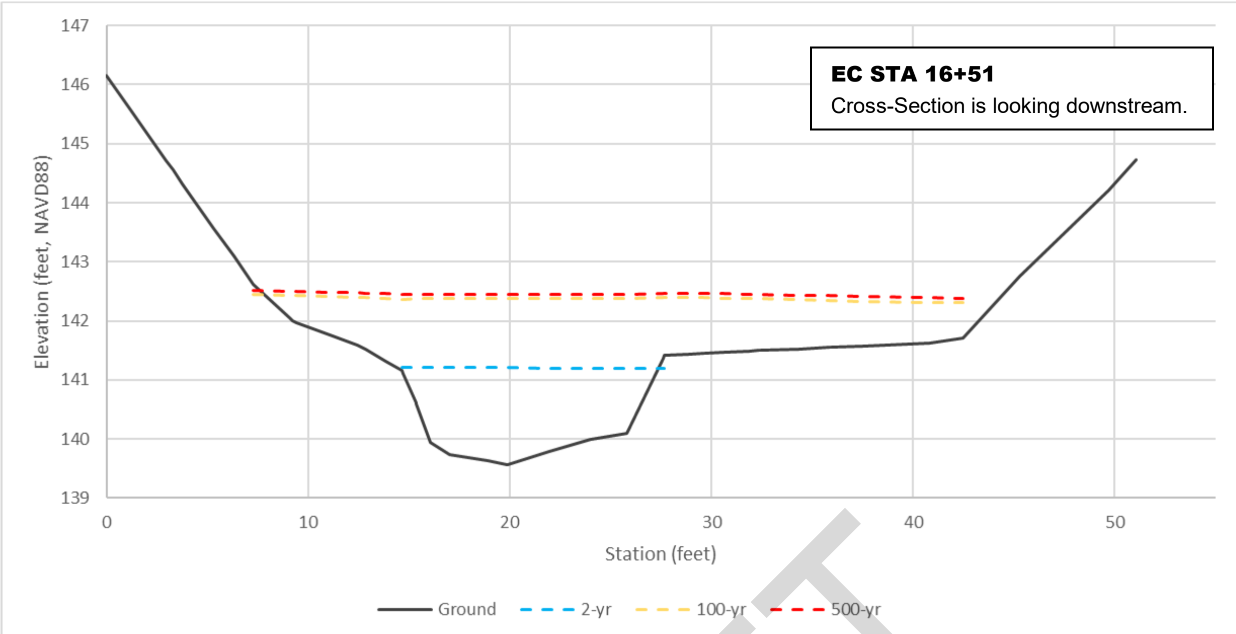

Figure 63: Typical upstream existing channel cross section (STA 16+51)

Under the 100-year flow, channel velocities and shear stress are highest upstream between station 16+00 and 19+00, directly downstream of the culvert, and where flow in the roadside ditch overtops SR-307 (Figure 64 and Table 14). These are all areas of constriction, which include channel narrowing downstream of the culvert and the existing perched culvert.

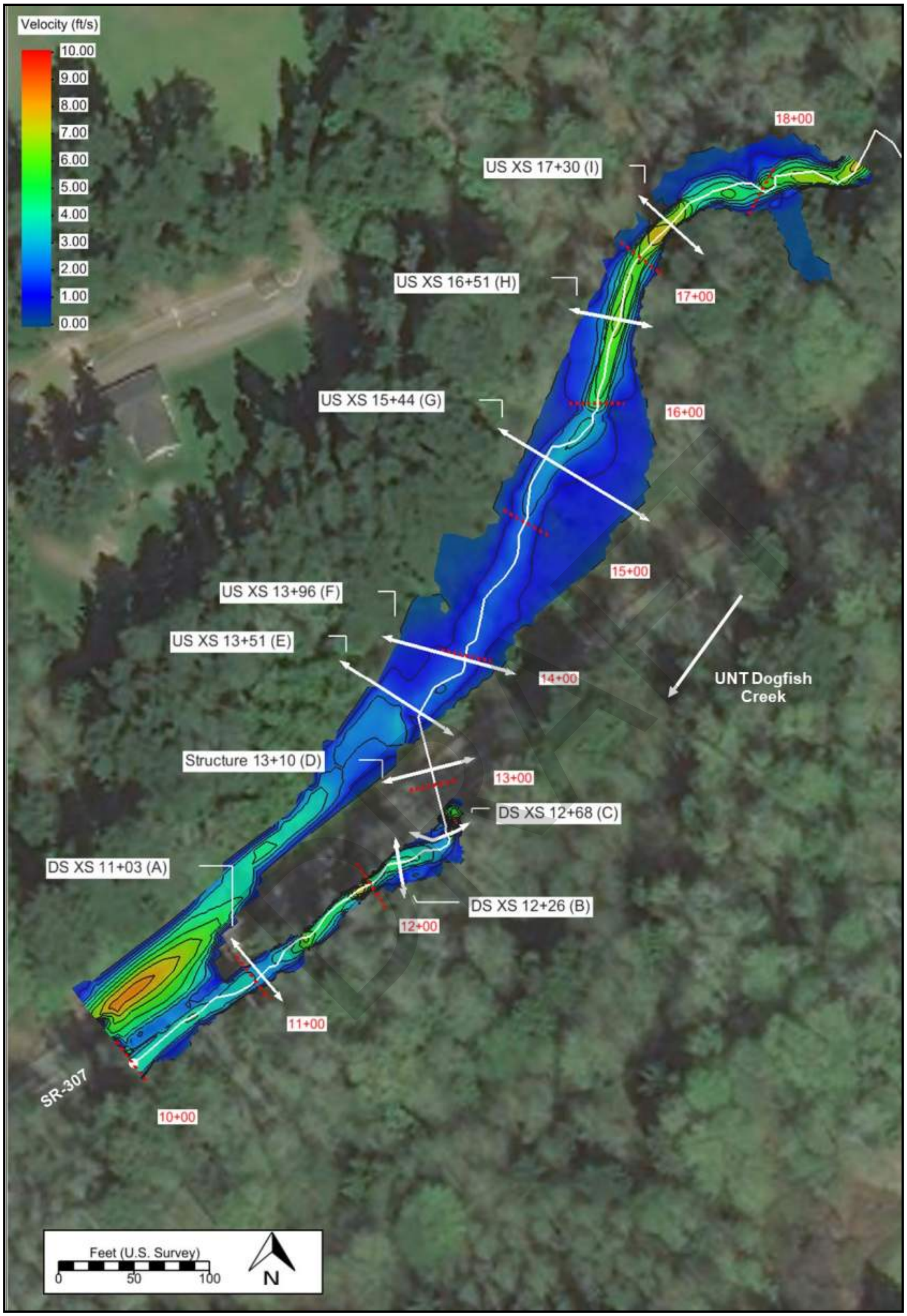

Figure 64: Existing-conditions 100-year velocity map with cross-section locations

Table 15: Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities tributary scenario (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS 11+03 (A)	1.9	2.5	NA
DS 12+26 (B)	1.8	3.7	1.2
DS 12+68 (C)	2.9	2.3	0.6
Structure 13+10 (D)	NA	NA	NA
US 13+51 (E)	0.6	1.6	1.5
US 13+96 (F)	0.5	1.6	1.0
US 15+44 (G)	0.9	2.4	0.6
US 16+51 (H)	2.2	5.8	2.1
US 17+30 (I)	NA	5.6	0.0

Right overbank (ROB)/left overbank (LOB) locations were approximated using existing survey break lines.

5.3 Natural Conditions

A natural conditions model is required for unconfined streams, defined as having a Floodplain Utilization Ratio greater than 3.0 (Section 2.7.2.1) (WSDOT 2022a). The model is intended to represent the hydraulic conditions of the project reach if roadway and infrastructure were to be removed entirely. Comparing the proposed and natural conditions main channel velocities can be used to validate proposed minimum hydraulic opening width (Section 4.1) (WSDOT 2022a). Development of the natural conditions design is discussed in Section 4.1.

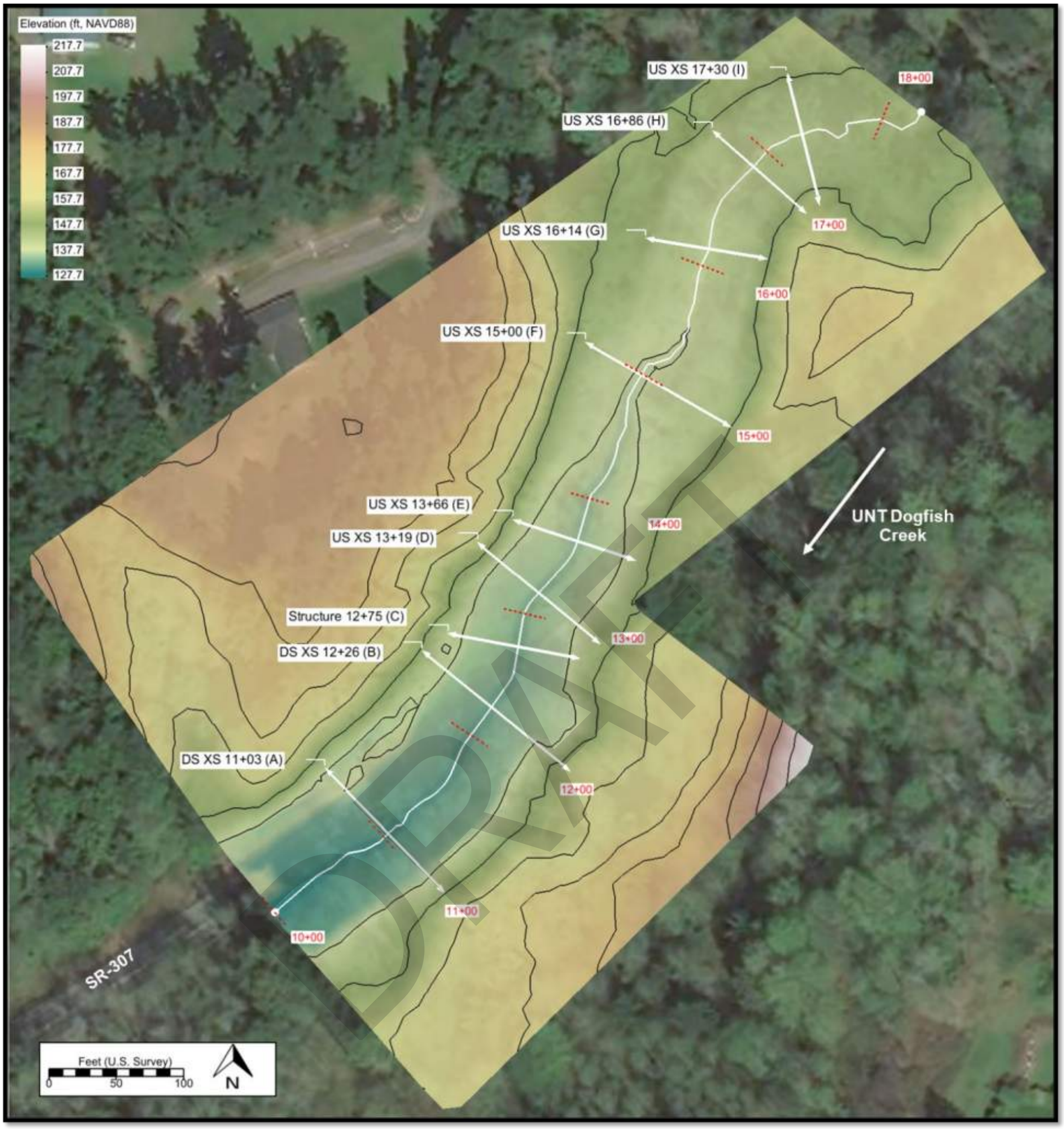

Figure 65: Locations of cross sections used for natural conditions results reporting

A 70-foot-wide graded cross section (mimicking the same main channel design as proposed conditions with added floodplain bench width [Figure 63]) was used to model natural conditions in the absence of SR-307 and the relic gravel road located to the north of UNT to Dogfish Creek (Figure 65). Outside of this cross section, 2:1 grading is enforced to tie-in locations in efforts to match an average valley bottom width, essentially removing the hydraulic effect of the existing roadways. Refer to Section 4.1 for natural conditions design development.

Hydraulic results for the natural conditions model were extracted from nine cross sections with similar spatial distribution as the existing and proposed conditions models (Figure 65). Stationing of the selected cross sections fluctuate slightly due to differences in alignments.

Average main channel hydraulic results for each cross section are represented in Table 16. Average water surface elevation, maximum depth, average main channel velocity, and average shear stress remain relatively the same throughout the modeled reach under 2-, 100-, 500-, and 2080 predicted 100-year flow events (Table 16 and Figure 62).

Table 16: Average main channel hydraulic results for natural conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year	2080 Predicted 100-yr
Average WSE (ft)	DS 11+03 (A)	131.2	132.3	132.4	132.9
	DS 12+26 (B)	133.4	134.5	134.6	135.1
	Structure 12+75 (C)	134.3	135.4	135.5	135.9
	US 13+19 (D)	135.1	136.2	136.3	136.7
	US 13+66 (E)	135.9	137.1	137.1	137.6
	US 15+00 (F)	138.4	139.6	139.6	140.1
	US 16+14 (G)	140.4	141.5	141.6	142.0
	US 16+86 (H)	141.7	142.8	142.9	143.4
	US 17+30 (I)	142.5	143.7	143.8	144.2
Max depth (ft)	DS 11+03 (A)	1.7	2.8	2.9	3.4
	DS 12+26 (B)	1.6	2.8	2.9	3.3
	Structure 12+75 (C)	1.6	2.8	2.9	3.3
	US 13+19 (D)	1.6	2.8	2.9	3.3
	US 13+66 (E)	1.6	2.8	2.9	3.3
	US 15+00 (F)	1.7	2.9	3.0	3.4
	US 16+14 (G)	1.7	2.8	2.9	3.3
	US 16+86 (H)	1.6	2.8	2.9	3.3
	US 17+30 (I)	1.7	2.9	2.9	3.4
Average velocity (ft/s)	DS 11+03 (A)	3.7	4.9	5.0	5.3
	DS 12+26 (B)	3.7	5.1	5.2	5.5
	Structure 12+75 (C)	3.7	5.2	5.2	5.6
	US 13+19 (D)	3.7	5.2	5.2	5.6
	US 13+66 (E)	3.7	5.1	5.2	5.5
	US 15+00 (F)	3.5	4.7	4.7	5.2
	US 16+14 (G)	3.8	5.1	5.2	5.6
	US 16+86 (H)	3.7	5.0	5.1	5.5
	US 17+30 (I)	3.5	4.5	4.6	5.0
Average shear (lb/SF)	DS 11+03 (A)	1.2	2.0	2.0	2.1
	DS 12+26 (B)	1.3	2.1	2.1	2.4
	Structure 12+75 (C)	1.3	2.1	2.2	2.4
	US 13+19 (D)	1.2	2.2	2.2	2.4
	US 13+66 (E)	1.3	2.1	2.2	2.4
	US 15+00 (F)	1.1	1.9	1.9	2.2
	US 16+14 (G)	1.3	2.2	2.2	2.5
	US 16+86 (H)	1.3	2.1	2.1	2.4
	US 17+30 (I)	1.2	1.7	1.7	2.0

Main channel extents were approximated using topographic break lines

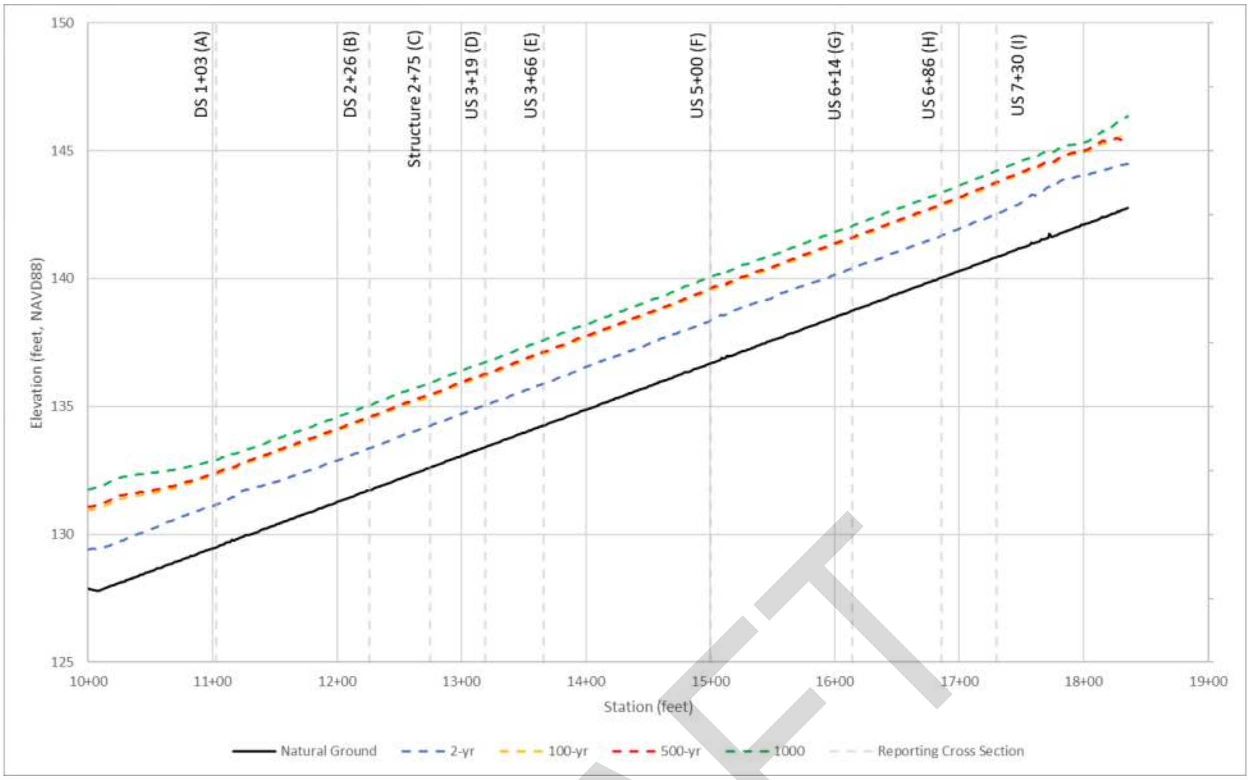

Figure 66: Natural-conditions water surface profiles

As shown in Figure 67, the 2-year flow appears to be spilling onto the floodplain benches. At the 100-, 500-, and 2080 predicted 100-year events, flow is contained within bench limits, moving through gentle meanders. Average main channel velocity for these flows range between 4.7 ft/s to 5.2 ft/s for the 100-year, 4.6 ft/s to 5.2 ft/s for the 500-year, and 5.0 ft/s to 5.6 ft/s for the 2080 predicted 100-year flows. Floodplain velocities during the 100- and 2080 predicted 100-year flows are relatively slow, ranging between 1.3 ft/s and 2.5 ft/s (Table 17). Shear stress never exceeds 3 lbs/ft^2 and is highest in the upstream portion of the modeled reach.

Average main channel velocity immediately upstream of the structure is about 5.2 ft/s if the roadway fill were to be removed completely. This is like average main channel velocities observed near STA 16+50 and 17+30 in the existing conditions model (Table 15). Results from this natural conditions model were used to backcheck the viability of the proposed minimum hydraulic opening via comparison of main channel velocities (Section 4.2.2). It was determined that proposed conditions main channel velocities do not exceed those in the natural conditions model by more than 10 percent (Table 17, Table 19, and Section 5.4).

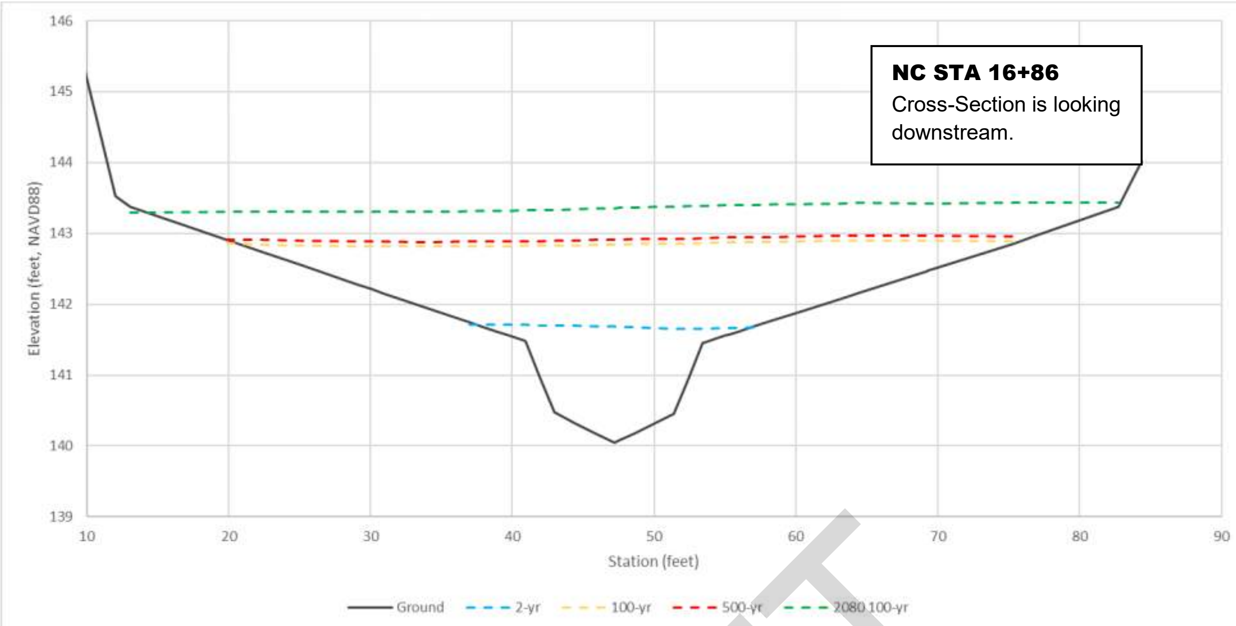

Figure 67: Typical upstream natural channel cross section (STA 16+86)

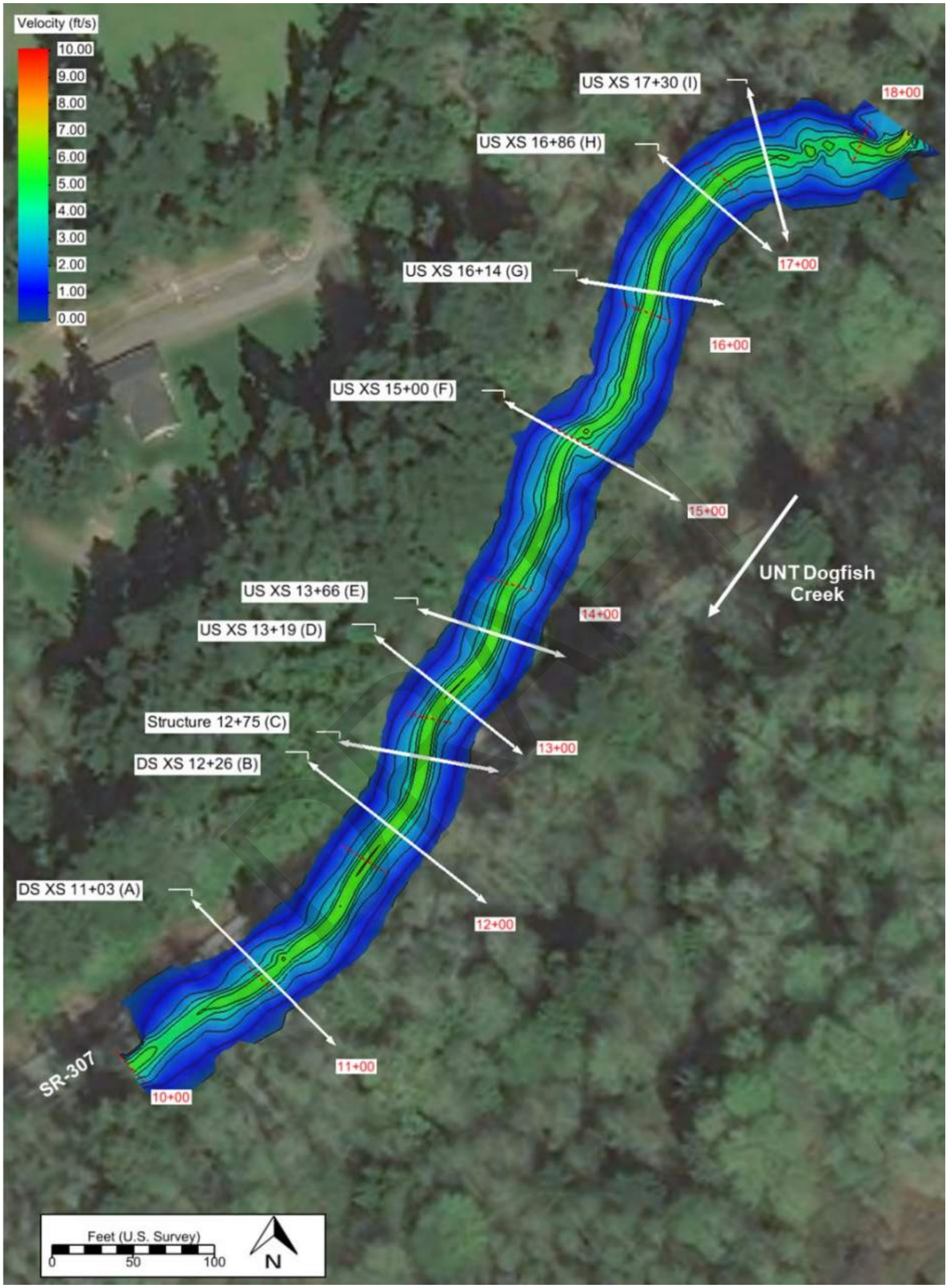

Figure 68: Natural-conditions 100-year velocity map with cross-section locations

Table 17: Natural-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 11+03 (A)	1.7	4.9	1.9	2.1	5.3	2.4
DS 12+26 (B)	1.9	5.1	1.5	2.4	5.5	1.8
Structure 12+75 (C)	1.3	5.2	2.1	1.7	5.6	2.6
US 13+19 (D)	1.9	5.2	1.4	2.6	5.6	1.6
US 13+66 (E)	1.4	5.1	2.0	1.6	5.5	2.5
US 15+00 (F)	2.5	4.7	1.5	3.0	5.2	1.5
US 16+14 (G)	1.3	5.1	2.1	1.6	5.6	2.6
US 16+86 (H)	1.4	5.0	2.0	2.0	5.5	2.4
US 17+30 (I)	2.2	4.5	1.7	2.6	5.0	2.0

Right overbank (ROB)/left overbank (LOB) locations were approximated by inspection of the topographic grade breaks.

5.4 Proposed Conditions: 36-foot Minimum Hydraulic Width

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic modeling assumes vertical walls at the edge of the minimum hydraulic width unless otherwise specified. See Section 4.2.2 for a description of how the minimum hydraulic width was determined.

For this crossing, a minimum hydraulic opening of 17 feet was determined to be a starting point (Section 4.2.2). The proposed conditions SRH-2D model evaluates hydraulic conditions with a proposed crossing that has a 36-foot-wide hydraulic opening for the 2-, 100-, 500-, and 2080 predicted 100-year peak flows. This width matches the calculated 2080 100-year flow top width through the crossing structure, which is modeled as an open channel (Figure 71). Five hundred-year event flows do not exceed flood widths greater than 36 feet through the crossing structure. Hydraulic results were extracted along the profile at similar locations to existing conditions, as described in Section 5.2, and at a typical cross section through the proposed structure (Figure 71). Appendix H contains additional cross-sectional results as well as plan views of hydraulic results summarized in Table 18.

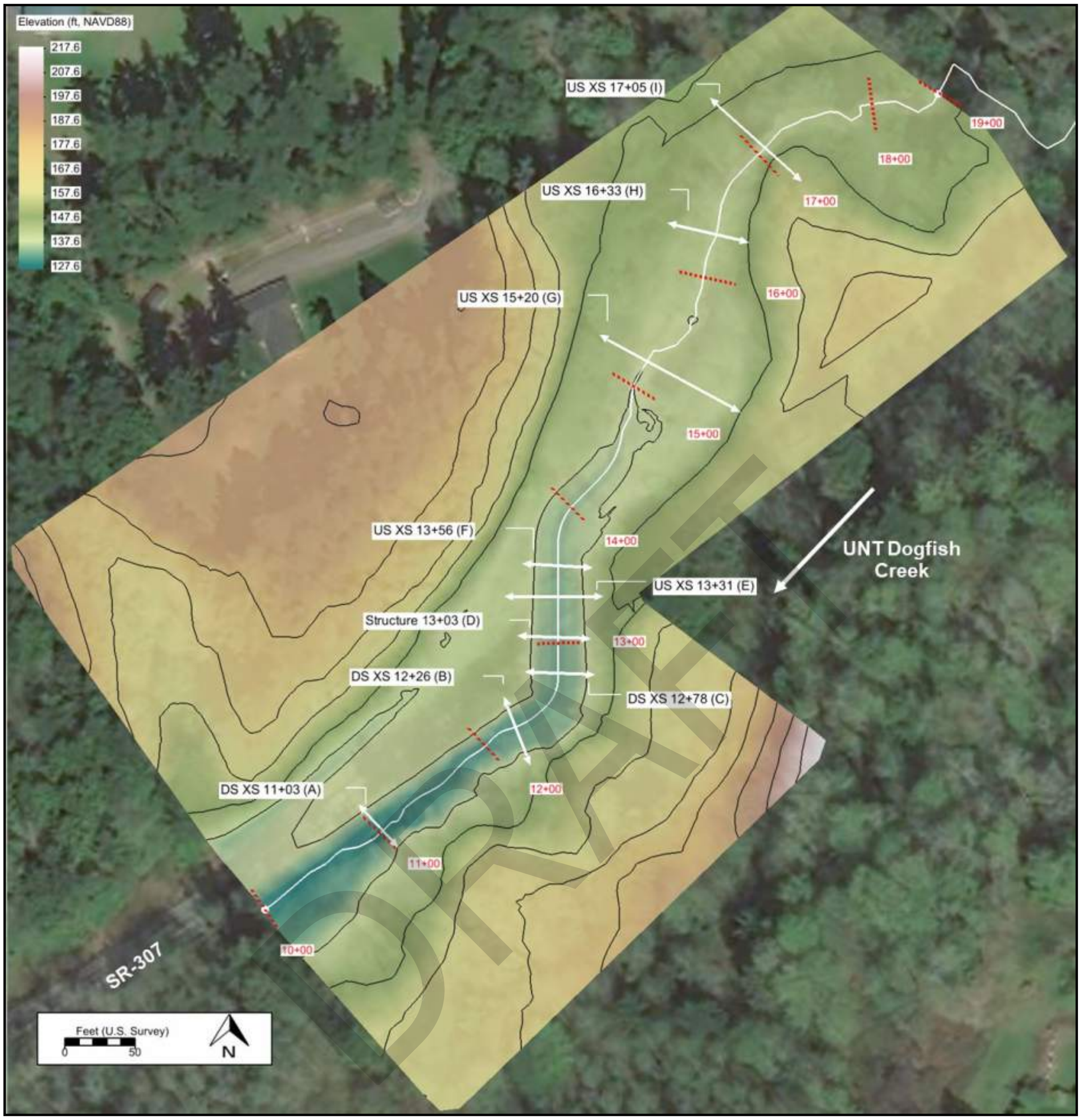

Figure 69: Locations of cross sections on proposed alignment used for results reporting

Under proposed conditions, flow during the 2-year event through the graded reach overtops the channel banks, inundating portions of the designed 6-foot floodplain benches (Appendix H). Upstream of the graded reach, flow spills over a 50-foot side channel bench near station 15+00, creating a diverse velocity regime. Through the graded reach, the 100- and 500-year flows completely inundate the floodplain benches, with no flow being diverted to the roadside ditch (Figure 71, Figure 72, Appendix H). At the upstream and downstream tie-in locations within the graded reach, flow is contained within the catch slopes and water surface profiles indicate that the proposed design does not cause backwater upstream of the proposed crossing during any modeled flows (Figure 70).

Maximum depth, average velocity, and average shear stress in cross sections not affected by grading or backwatering in both the proposed and existing conditions models are similar (Cross sections A, H, and I for the 2-, 100-, and 500-year events) (Table 18). This suggests the proposed conditions model adequately reproduces design reach hydraulics. Maximum depths are shallower under proposed conditions due to expansion of floodplain benches and removal of the existing undersized culvert. Maximum depth through the structure is approximately 0.5 feet deeper than that modeled under natural conditions (Table 16). This is likely influenced by proposed habitat complexity (i.e., LWM and meander bars) and the absence of catch slopes in the natural condition that are present through the proposed structure, where the natural conditions model illustrates flow distributed across wide floodplain benches (Figure 67).

Average main channel velocities are slightly higher upstream of the crossing and lower throughout crossing between proposed and existing conditions. The decrease in velocity can be attributed to the proposed addition of LWM through the graded reach and meander bars through the crossing. Increased velocity will be seen in areas that were affected by backwater in existing conditions and are not under proposed conditions. In comparison to the natural conditions model, average main channel velocities are about 2 feet per second lower (Table 16). This is also likely due to proposed habitat complexity and a gentler gradient through the proposed crossing.

Average shear stress values are higher under proposed conditions due to addition of LWM and an increase in channel slope (Cross sections C, D, E, and F in Table 18). Average main channel hydraulic results for proposed conditions under 100- and 500-year events are comparable to one another, suggesting the proposed channel will not significantly alter the existing bed mobility characteristics (Section 5.2).

Table 18: Average main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year	2080 Predicted 100-year
Average WSE (ft)	DS 11+03 (A)	130.8	132.5	132.6	133.3
	DS 12+26 (B)	133.2	135.0	135.1	136.0
	DS 12+78 (C)	134.0	135.6	135.7	136.6
	Structure 13+03 (D)	134.6	136.0	136.1	136.9
	US 13+31 (E)	135.2	136.5	136.6	137.4
	US 13+56 (F)	135.7	137.0	137.1	137.8
	US 15+20 (G)	140.0	141.0	141.0	141.4
	US 16+33 (H)	141.3	142.4	142.5	142.9
	US 17+05 (I)	142.2	143.6	143.7	144.4
Max depth (ft)	DS 11+03 (A)	2.4	4.1	4.2	5.0
	DS 12+26 (B)	2.3	4.1	4.2	5.1
	DS 12+78 (C)	2.0	3.6	3.7	4.6
	Structure 13+03 (D)	2.0	3.4	3.5	4.4
	US 13+31 (E)	2.0	3.3	3.4	4.2
	US 13+56 (F)	2.0	3.3	3.4	4.1
	US 15+20 (G)	2.2	3.2	3.3	3.6
	US 16+33 (H)	1.7	2.8	2.9	3.4
	US 17+05 (I)	2.2	3.5	3.6	4.5
	DS 11+03 (A)	1.8	3.2	3.1	3.9

Hydraulic parameter	Cross section	2-year	100-year	500-year	2080 Predicted 100-year
Average velocity (ft/s)	DS 12+26 (B)	1.8	2.9	3.0	3.5
	DS 12+78 (C)	1.9	3.1	3.2	3.5
	Structure 13+03 (D)	1.9	3.3	3.4	3.8
	US 13+31 (E)	1.9	3.2	3.3	3.6
	US 13+56 (F)	1.9	3.5	3.6	4.1
	US 15+20 (G)	2.8	3.7	3.8	4.2
	US 16+33 (H)	3.5	5.7	5.8	6.7
	US 17+05 (I)	3.3	5.3	5.5	6.7
Average shear (lb/SF)	DS 11+03 (A)	0.9	2.1	2.1	3.0
	DS 12+26 (B)	0.9	1.6	1.7	2.1
	DS 12+78 (C)	1.2	2.1	2.1	2.3
	Structure 13+03 (D)	1.2	2.5	2.6	3.0
	US 13+31 (E)	1.2	2.4	2.5	2.8
	US 13+56 (F)	1.2	2.7	2.8	3.4
	US 15+20 (G)	2.2	3.1	3.1	3.7
	US 16+33 (H)	1.0	1.9	1.9	2.4
	US 17+05 (I)	0.8	2.0	2.1	2.6

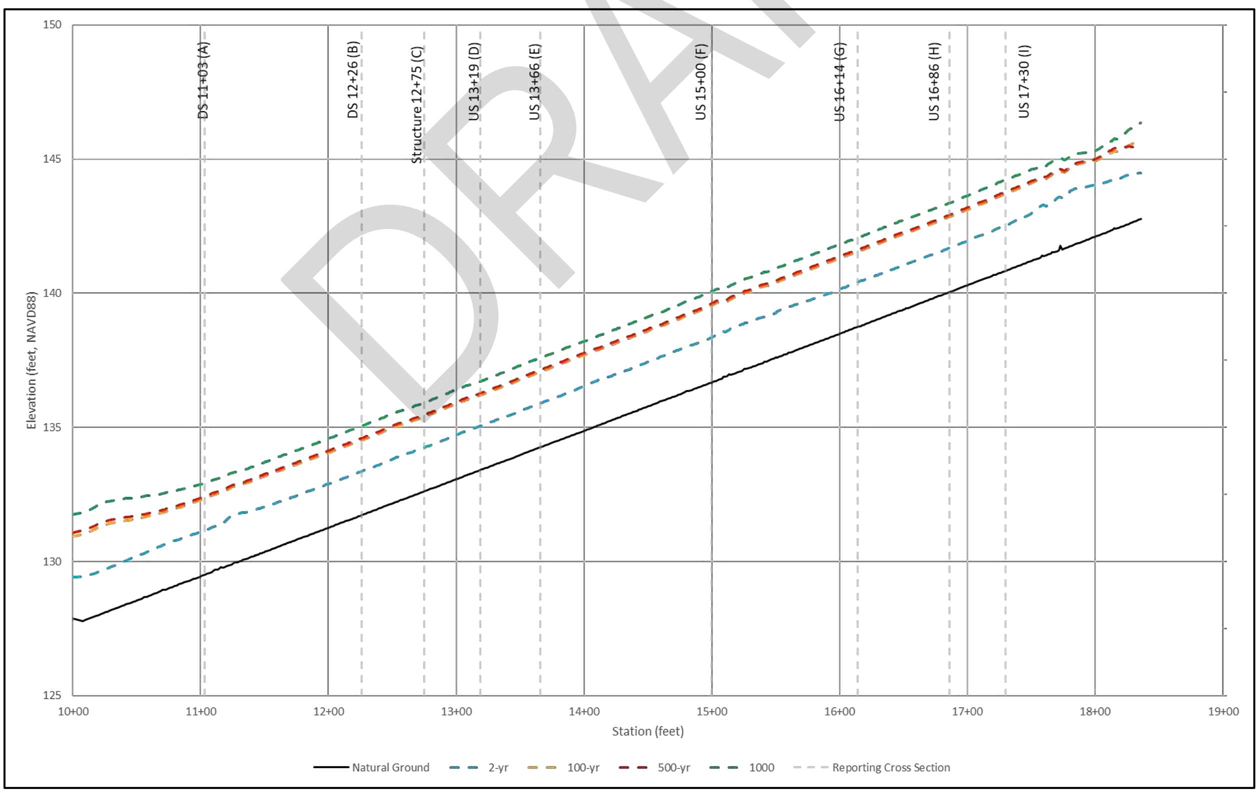

Figure 70: Proposed-conditions water surface profiles

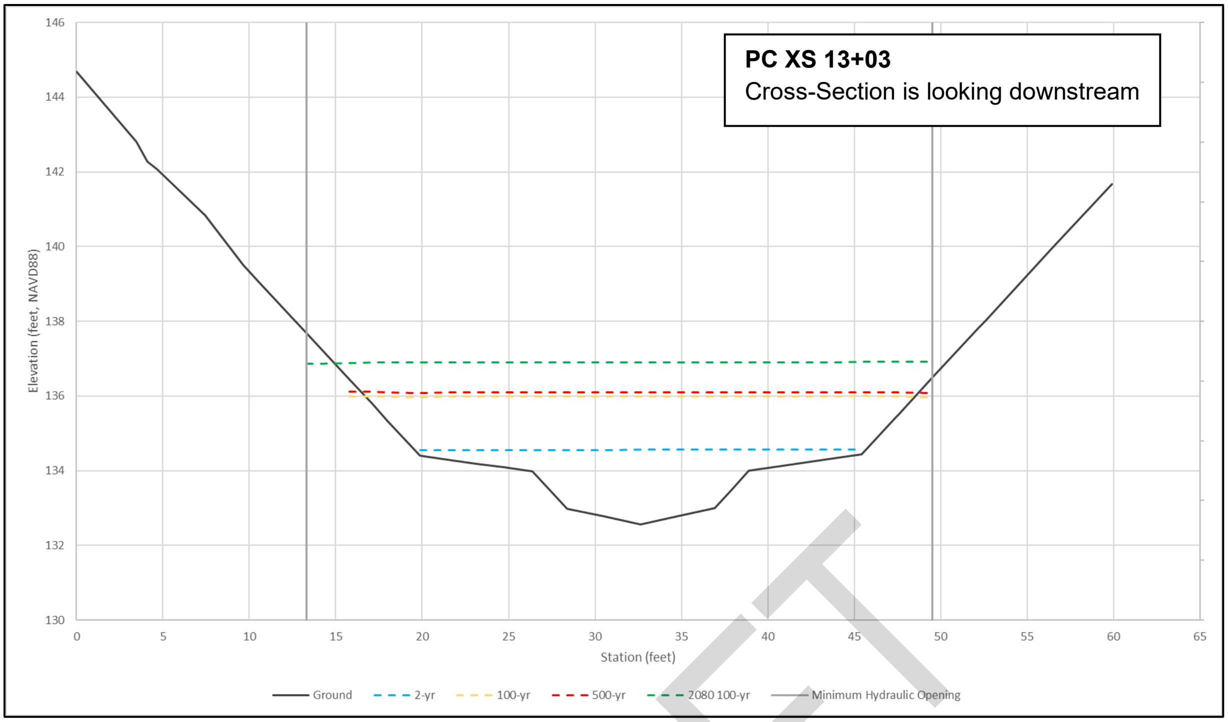

Figure 71: Typical section through proposed structure (STA 13+03) looking downstream

Main channel velocities in proposed conditions during the 100-year event (Figure 72, Table 18, and Table 19) are similar to existing conditions in the design reaches (Figure 64, Table 14, and Table 15), with the exception of backwatered areas under existing conditions, which experience increased velocities. Overbank velocities are higher under proposed conditions due to the entire flow being routed through the crossing as opposed to some flow being diverted down the roadside ditch under existing conditions. These overbank areas will provide high flow refugia, and the addition of LWM and meander bars will also provide a diverse regime for rest.

Two-, 100-, and 500-year top widths within the reference reach are similar between proposed and existing conditions. This is most apparent between Cross Section H at STA 16+33 in proposed conditions and Cross Section H at STA 16+51 in existing conditions (Appendix H). The 2-year top width is just about to activate the floodplain, where the 100- and 500-year top widths are actively spilling onto the floodplain benches. This suggests that the proposed channel shape is promoting continuity and not causing impacts further upstream. Cross section H and I across proposed, existing, and natural conditions are the best examples within the reference reach to compare hydraulic results (Appendix H).

Results from the proposed conditions model were used to inform the minimum hydraulic opening and check for continuity through the modeled reach. The design team originally started with an MHO of 16 feet. This was then increased to 36 feet to span the 2080 projected 100-year top width. Main channel velocities under proposed conditions were then compared to those under natural conditions to check the viability of the proposed minimum hydraulic opening (Table 7 in Section 4.2.2). Velocity ratios (proposed/natural) at the reference reach and at the structure range from 0.6 to 0.8, satisfying WSDOT’s guidance (WSDOT 2022a).

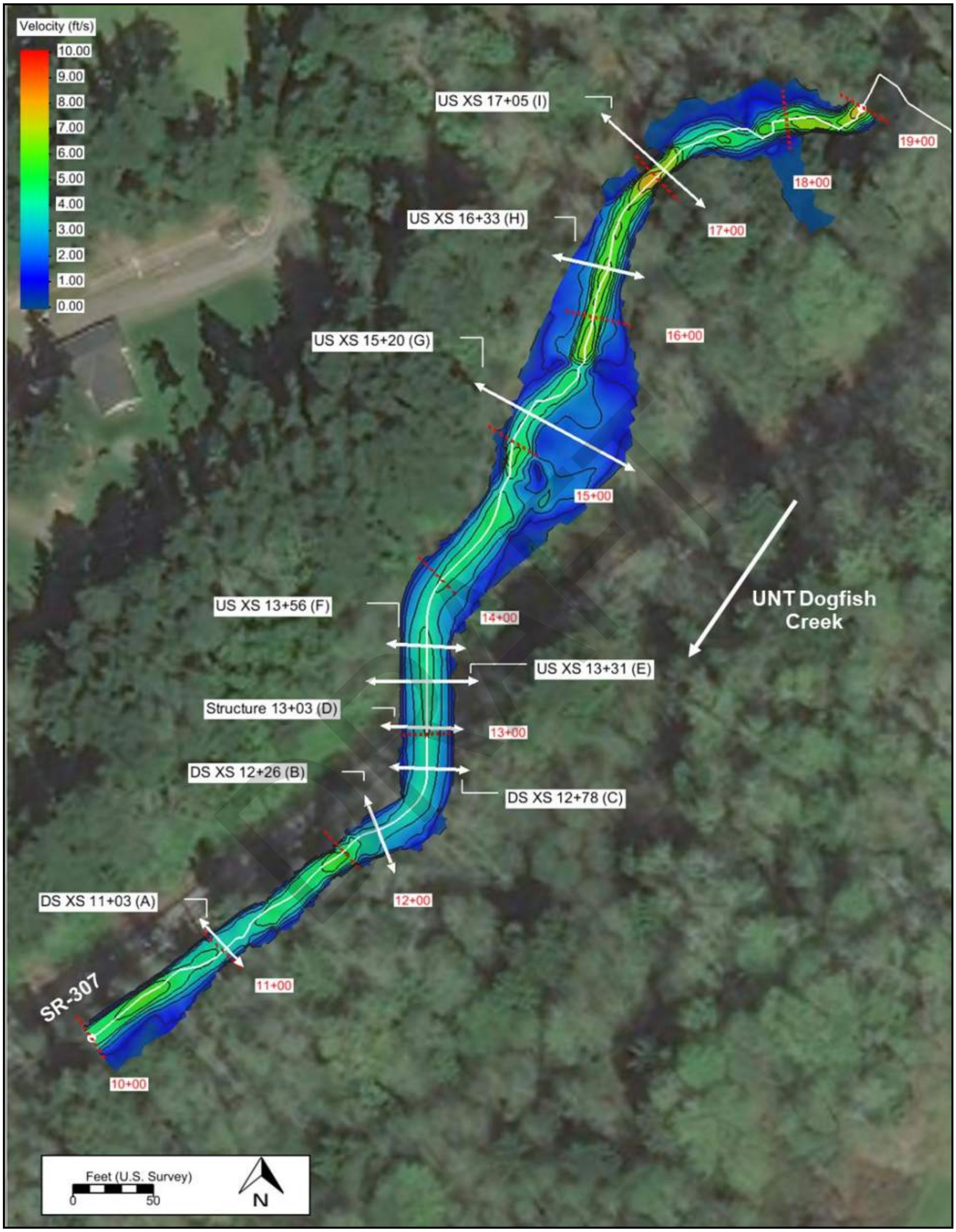

Figure 72: Proposed-conditions 100-year velocity map

Table 19: Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 11+03 (A)	NA	3.2	1.0	0.0	3.9	2.2
DS 12+26 (B)	1.8	2.9	0.8	2.2	3.5	1.5
DS 12+78 (C)	1.1	3.1	0.8	1.4	3.5	2.0
Structure 13+03 (D)	1.2	3.3	1.1	1.5	3.8	2.0
US 13+31 (E)	1.7	3.2	NA	1.8	3.6	NA
US 13+56 (F)	1.5	3.5	1.4	1.4	4.1	2.6
US 15+20 (G)	1.6	3.7	1.6	2.2	4.2	1.7
US 16+33 (H)	2.3	5.7	2.1	3.4	6.7	3.1
US 17+05 (I)	NA	5.3	0.0	NA	6.7	0.2

Right overbank (ROB)/left overbank (LOB) locations were approximated by inspection of topographic break lines.

6 Floodplain Evaluation

This project is not within a FEMA special flood hazard area (SFHA); see Appendix A for FIRMette. The existing-project and expected proposed-project conditions were evaluated to determine whether the project would cause a change in flood risk.

6.1 Water Surface Elevations

The difference between the 100-year water surface profile along the existing and proposed surfaces is illustrated in Figure 73. Upstream of crossing 991999, there is a significant decrease in water surface elevations (WSE) following the reduction of backwater under proposed conditions. The increase in WSE downstream of the crossing under proposed conditions is the re-introduction of flow to the main channel which was diverted through the roadside ditch under existing conditions for the 100- and 500-year flows (Figure 64). One hundred-year event water surface elevations (along both the existing and proposed alignments) converge upstream of the culvert at approximately station 16+45.

Downstream, the 100-year WSEs do not converge within the survey extents due to the additional roadside ditch boundary condition opposite the main channel that is conveying portions of flow under the existing conditions 100-year event (Section 5.1.4). The proposed minimum hydraulic opening passes all flow within the main channel downstream of the proposed structure. Convergence likely occurs where the roadside ditch flow renters UNT to Dogfish Creek downstream of the survey extents.

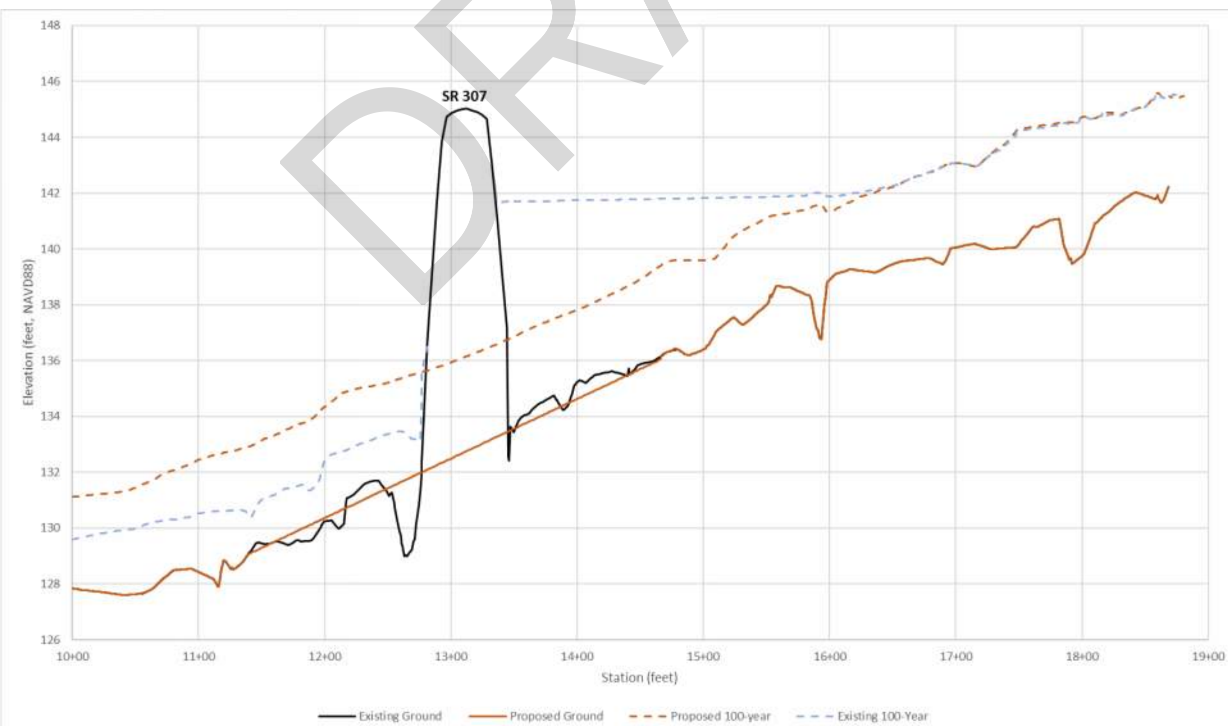

Figure 73: Existing- and proposed-conditions 100-year water surface profile comparison along proposed alignment

The difference between existing and proposed conditions 100-year water surface elevations is compared spatially in Figure 74. Positive values, shaded in red, denote areas that are expected to increase in water surface elevation (become deeper or newly inundated) under proposed conditions versus existing. Blue shaded areas then denote areas expected to decrease in water surface elevation (become shallower or newly dried). Decreases are connected to the replacement of the existing undersized culvert, thus allowing flow to travel through the crossing without backwatering and deflecting through a roadside ditch. Another notable decrease is located at the existing culvert's outlet, where a large scour pool will be filled and tied into the proposed grading. Increases in WSE occur mostly downstream of the existing crossing, which is expected to convey all flow, without major overflows into the roadside ditch. The addition of LWM and meander bars within the graded channel and through the crossing increases roughness and may contribute to a rise in WSE under proposed conditions. No properties or infrastructure were identified at the project site that would be affected by changes in floodplain surface water elevations or floodplain storage. A flood risk assessment will be developed during later stages of the design.

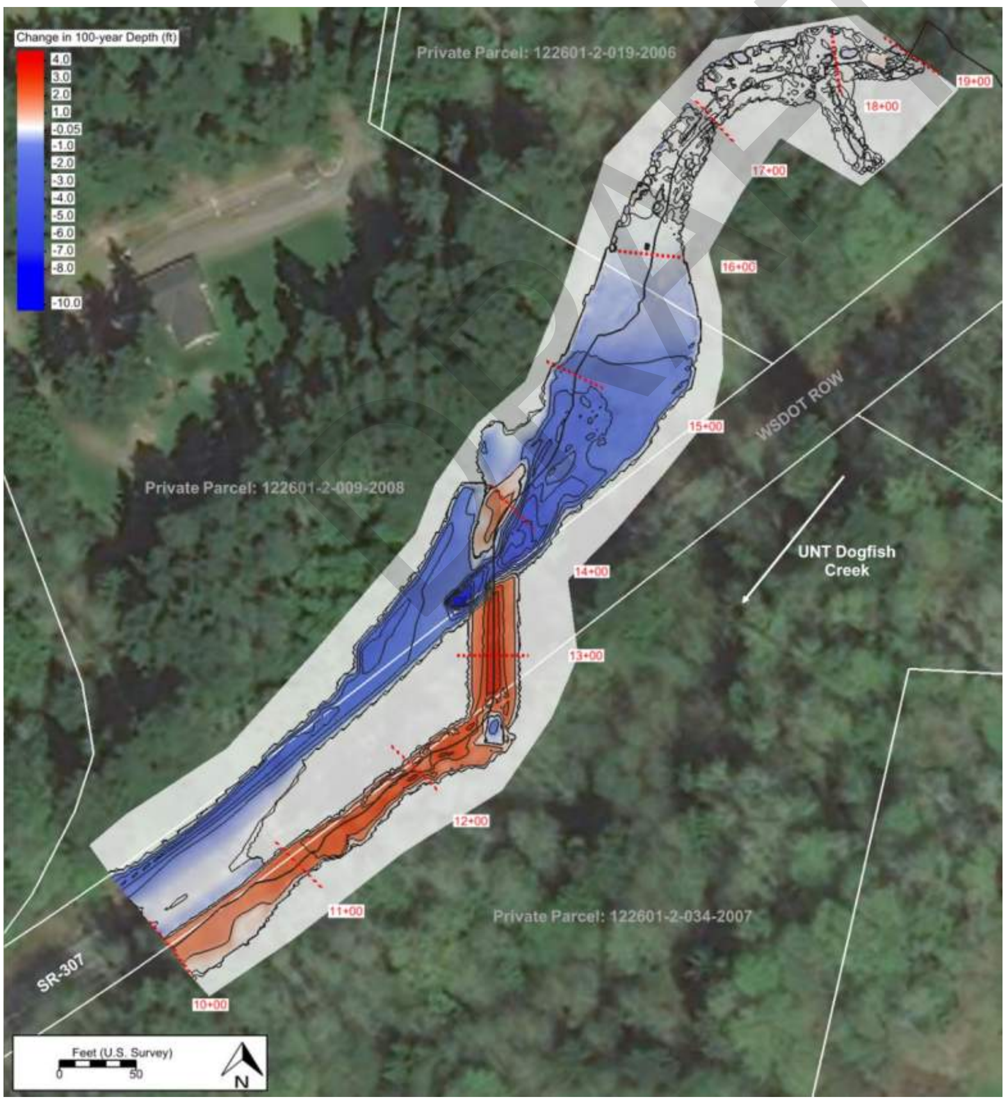

Figure 74**: 100-year WSE change from existing to proposed conditions** ***(Project extent not within a FEMA SFHA)***

7 Preliminary Scour Analysis

For this preliminary phase of the project, the risk for lateral migration, potential for long-term degradation and evaluation of preliminary total scour is based on available data, including but not limited to LiDAR data (WSDNR 2022), geotechnical boring logs (WSDOT 2022d), site visit summaries (Appendix B), and WSDOT's ground survey performed in winter of 2021. This evaluation is to be considered preliminary and is not to be taken as a final recommendation.

Using the results of the hydraulic analysis (Section 5.4), based on the recommended minimum hydraulic opening, and considering the potential for lateral channel migration, preliminary scour calculations for the 2-year, 10-year, 100-year, 500-year, and projected 2080 100-year flood events were performed following the guidance in the Federal Highway Administration (FHWA) documents HEC-18 and HEC-23 (FHWA 2009), and in the Integrated Streambank Protection Guidelines (WDFW 2003) as discussed in the following sections. Data for computing contraction scour and abutment scour were exported from SMS (Aquaveo 2022) to the FHWA software Hydraulic Toolbox version 5.1 (FHWA 2021) for calculations (Appendix K). The 2-year flood event was used to evaluate bend scour, with rationale discussed in Section 7.4.3.

Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour
    - Abutment
    - Bend

All considered scour components, apart from bend scour, use the 2080 100-year projected flood as both the scour design and check floods, as it creates the deepest scour (Table 20) (WSDOT 2022a). The 2-year flood event was used to evaluate bend scour, with rationale discussed in Section 7.4.3. In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. This assessment resulted in the inclusion of an estimated abutment scour condition as discussed in Section 7.4.2. These various scour components will be discussed in the following sections.

The projected 2080 100-year flow event serves as both the design and the check floods for these scour analyses as this discharge exceeds the 500-year flow and produces the deepest total scour. It is not anticipated that site and design hydraulic conditions are such that any flow below the design/check flood flow will result in greater total scour depths due to the trend shown in calculations that as discharge increases total scour depth increases and that no tailwater conditions are expected during other flows not modeled that would invalidate/alter this trend (Appendix K).

7.1 Lateral Migration

At the PHD stage, the risk from lateral channel migration to the proposed structure is assumed to occur unless a detailed evaluation of geotechnical data is available to reject this claim.

Variables considered for lateral migration at this stage include geotechnical boring logs and evaluation of dynamic physical processes that drive bank erosion.

Soils data from borings provided prior to completion of the geotechnical report indicates silty sand with gravel material extends approximately 15 feet below the road surface (WSDOT 2022d). Fine-grained glacial deposits of poorly graded sand with silt are recorded below this elevation, which would not eliminate lateral channel migration potential or reduce total computed scour depths over the anticipated life of the proposed structure (75-plus years). Soil assumptions will be revisited upon completion of geotechnical analysis and reporting.

As discussed in Section 2.7.5, undercut banks observed within the reference reach suggest lateral migration is not a low risk upstream of the proposed grading limits. The 70-foot average bench-to-bench floodplain width within the reference reach allows for channel movement and is approximately 200 feet upstream from the proposed structure. As the upstream thalweg moves towards SR-307, an abandoned gravel road grade exists along the right bank, where it's plausible to assume the stream could erode into and migrate towards during the lifetime of the structure. The upstream right bank wingwalls should extend beyond potential lateral migration limits or scour counter measures should be considered adjacent to the upstream right bank. Neither channel migration nor avulsion are anticipated downstream of the crossing as the placement of SR 307 is within a narrow valley corridor constraining the creek.

Observed lateral erosion upstream of the crossing suggests existing bed material may be more difficult to transport than existing bank material. Therefore, preferential erosion of bank material outside of the grading limits is likely to continue. The proposed median grain size (D_{50}) was designed to be mobile at stream flows greater than 2-year recurrence interval peak discharge (Appendix C). Because the bed and banks within the grading limits outside the structure will consist of similar material, preferential erosion is not necessarily applicable.

Placement of LWM will reduce flow velocities which drive bank erosion in these areas. Inside the structure, meander bars consisting of larger material than the bed will centralize flow to prevent entrainment and minimize the likelihood of lateral migration. The designed alignment will also avoid sharp turns, maintaining continuity of the planform.

7.2 Long-term Degradation of the Channel Bed

The creek appears near a vertical equilibrium based on the LiDAR data with an equilibrium slope of 1.8 percent that extends for a little over a mile (Figure 75). Compared to WSDOT survey data, the equilibrium slope based on LiDAR data is 1.4 feet higher (Section 2.7.4). A significant accumulation of debris has blocked the creek about 350 feet downstream of the culvert creating about a 4- to 5-foot drop in the profile. This blockage appears to have caused local deposition upstream and degradation downstream.

The accumulation should be considered temporary and will likely degrade or break loose within the lifetime of the new crossing. If this potential base level control (~STA 8+75) migrates upstream, it's likely it will stabilize around 1.8 percent, which may result in up to 3.0 feet of degradation through approximately STA 15+75 (Figure 75). It is assumed the base level location elevation follows the same offset trend observed between LiDAR and survey data. Therefore, the elevation of the base level control is approximately at 122.5 feet.

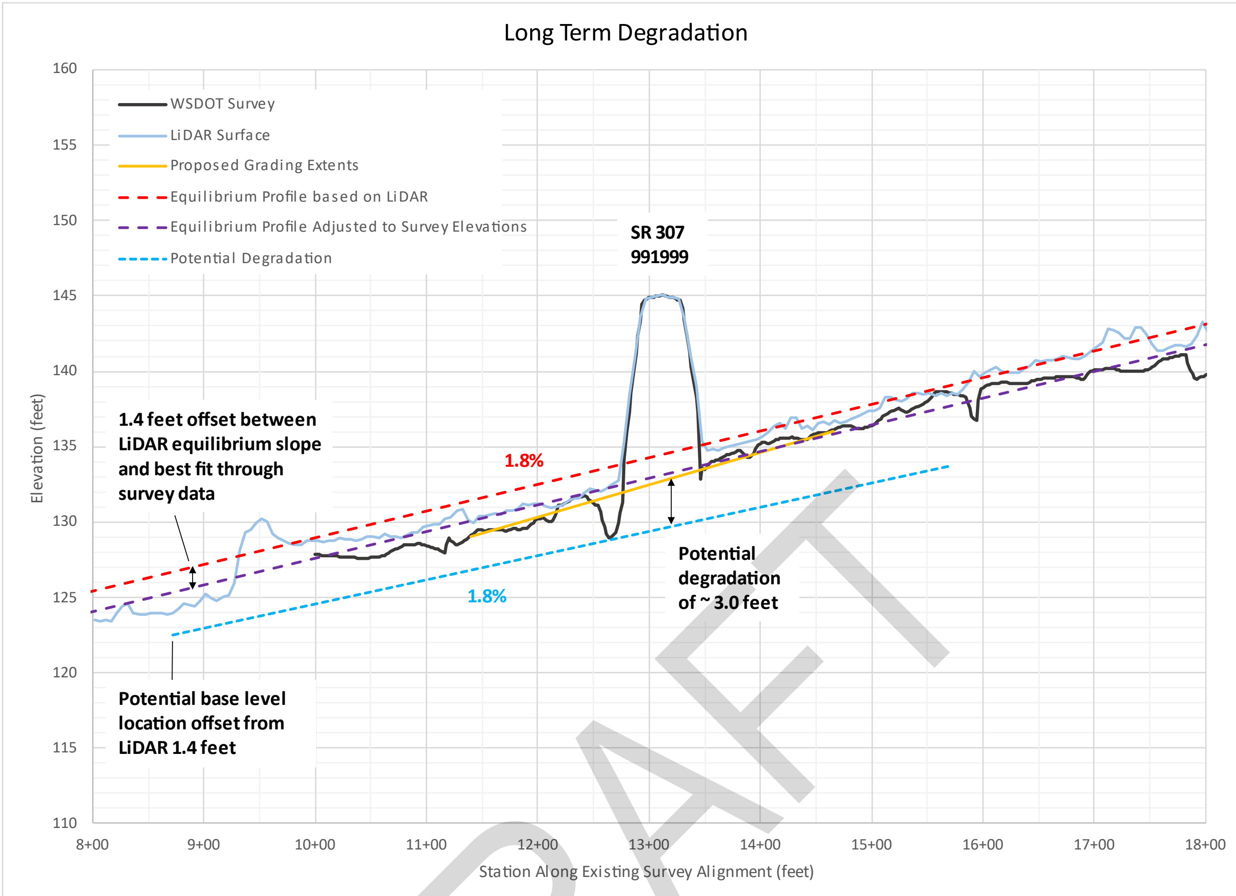

Figure 75: Potential long-term degradation at the proposed structure

7.3 Contraction Scour

This preliminary analysis of contraction scour does not account for features projecting into the flow, such as meander bar boulders in the channel through the hydraulic structure and LWM outside of the structure which have been modeled as a component of the composite channel roughness rather than in the terrain or as discrete roughness zones. These features may cause scour beyond which was calculated during this preliminary hydraulic design phase and this analysis should be refined during final hydraulic design.

The critical velocity index (CVI) method described in FHWA's *Two-Dimensional Hydraulic Modeling for Highways in the River Environment* (FHWA 2019) was used to evaluate contraction scour at crossing 991999 (Figure 76). This method illustrates the ratio between calculated flow velocity and the critical velocity which is a function of flow depth and median grain diameter. Values above one (shown in red) suggest the D_{50} is mobile while values less than one (shown in white) suggest the D_{50} is not mobile.

Figure 76 suggests clear water conditions exist under the scour design/check flood through the structure. Within FHWA's Hydraulic Toolbox, contraction scour was computed for clear water and live bed conditions to check this assumption. Recommended scour depths suggested clear water conditions, as the average upstream velocity does not exceed the critical velocity above which the median grain size and smaller will be transported (FHWA 2021). Determined similarly, the same expectation of clear water conditions hold true for the 10-, 100-, and 500- year flood events. Determined similarly, the same expectation of clear water conditions applies for the 10-, 100-, and 500- year flood events (Appendix K). Calculated contraction scour for the scour design/check flood equals 0.0 feet (Table 20).

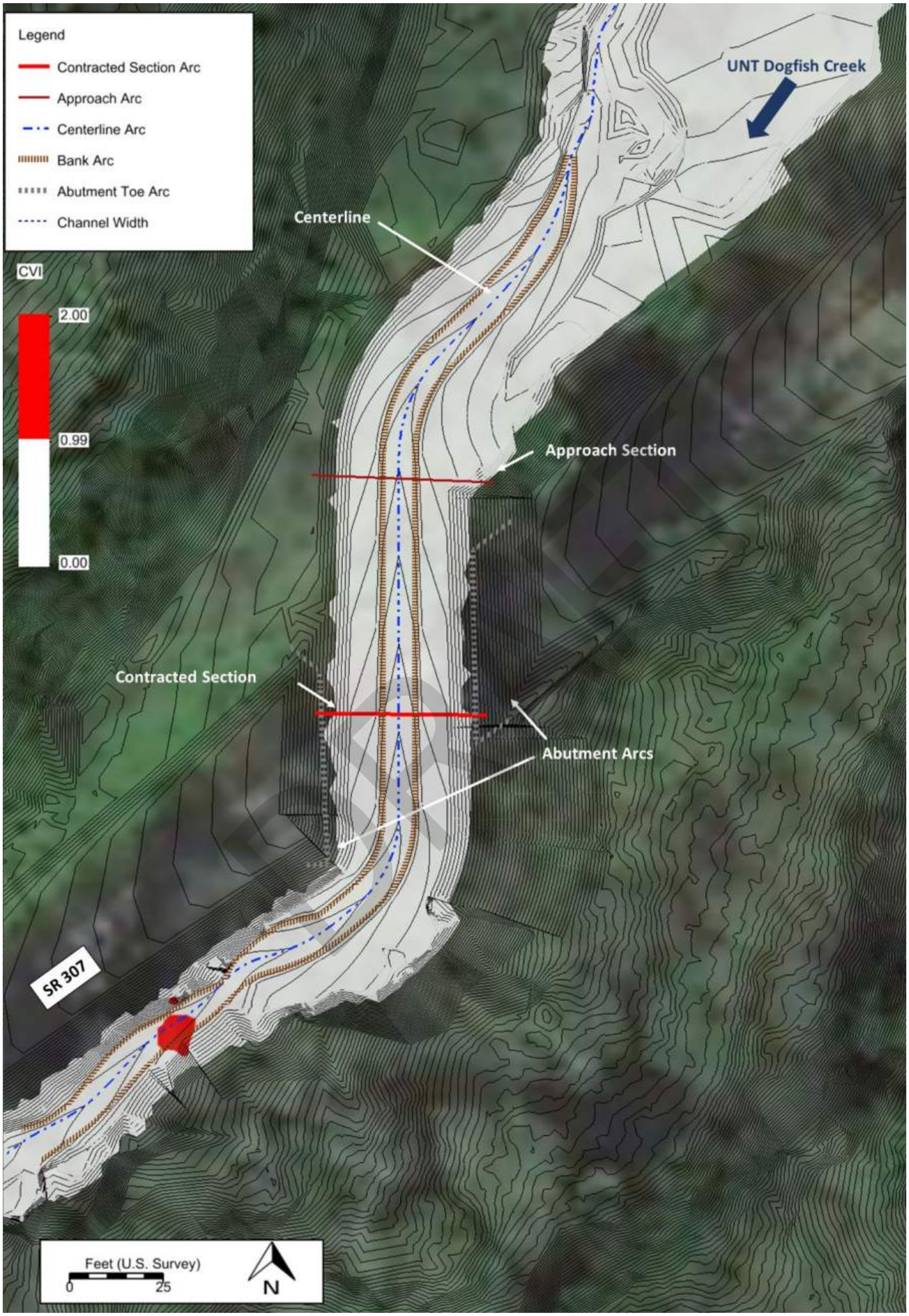

Figure 76: Proposed conditions 2080 predicted 100-year flow critical velocity index map

7.4 Local Scour

7.4.1 Pier Scour

The proposed 991999 structure will not have piers, so the pier scour component is not relevant and that component of local scour is assumed to be zero.

7.4.2 Abutment Scour

Abutment scour was estimated using the National Cooperative Highway Research Program (NCHRP) 24-20 approach for the scour design/check flood (FHWA 2012). The abutments and wingwalls for the proposed crossing are outside the computed water surface extents for all simulated flows up to the scour design/check flood. Although the SMS model does not currently show flow against the interior walls of the structure, abutment arcs were placed within the computed water surface extents to gather main channel hydraulics that may be applied to the abutments if lateral migration were to occur (Aquaveo 2022). These values were then exported to Hydraulic Toolbox to estimate abutment scour. As the wingwalls and abutments have not yet been designed, these were assumed to be vertical walls for the purpose of calculating abutment scour. Calculated abutment scour for the scour design/check flood equals 0.4 feet (Table 20).

7.4.3 Bend Scour

Bend scour occurs at the outsides of bends due to three-dimensional flow patterns not captured by the SRH-2D model developed for this project. However, bend scour can be estimated using section average results at a representative location upstream of the expected bend scour location () and the radius of curvature through the bend. The 2-year flow hydraulics were used to calculate bend scour because the three-dimensional flow patterns responsible for lowering the channel bed at the bend are not present when overbank depths exceed 20 percent of the channel depth (WDFW 2003). The proposed 2-year water surface is slightly above the top of bank, suggesting the selected discharge sufficiently captures a conservative scour depth. The two equations used to calculate bend scour during this analysis were Maynord's equation and Thorne's equation . Thorne's equation was selected as it can be applied to gravel-cobble systems making it appropriate for the proposed UNT Dogfish Creek channel while Maynord's equation is limited to sand bed channels with slopes less than 2-percent. Bend radii of curvature upstream and downstream of the proposed crossing range between 20 feet to 28 feet. A value of 26 feet was used as an input for the Maynord and Thorne equations, as it represents a typical bend near the crossing (Figure 77). Using these inputs, the computed bend scour was 2.4 feet (Table 20). A limitation of this analysis includes the omission of effects that upstream LWM has on flow patterns responsible for bend scour.

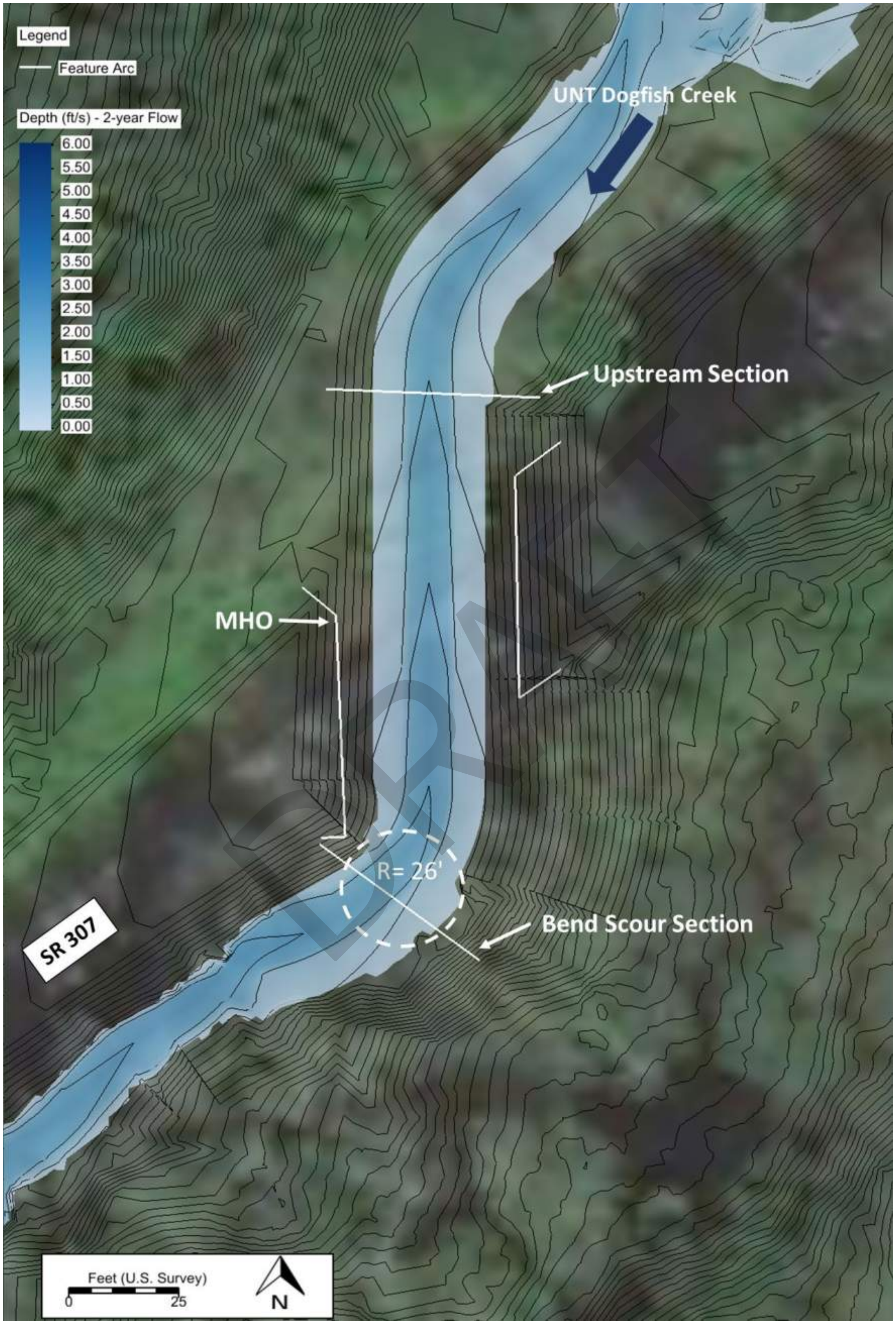

Figure 77: Locations of cross sections used for bend scour result reporting with 2-year flow depths

7.5 Total Scour

shows the calculated values for the scour design/check flood from the analyses discussed in the previous sections. Long-term degradation was found to be 3.0 feet. Contraction scour for all scenarios was determined to be zero, but this should be revisited at later design phases to directly account for the effects of meander bar boulders projecting into the main channel through the crossing.

Abutment scour was found to be approximately 0.4 feet for the scour design/check flood. The NCHRP method uses contraction scour as the starting calculation for abutment scour and then applies an amplification factor to represent large-scale turbulence that occurs in the vicinity of the abutment. Therefore, total depth of scour uses the greater of contraction or abutment scour (Table 20).

Bend scour calculated using 2-year hydraulics was conservatively assumed to be additive to other calculated types of scour to determine total depth of scour. The total depth of scour shown in Table 20 is defined relative to the channel thalweg elevation and assumed to apply to any location within the MHO.

Table 20: Scour analysis summary

Calculated Scour Components and Total Scour for SR 307 MP 1.34 UNT Dogfish Creek	
	Scour design[a]/check[b] flood
Long-term degradation (ft)	3.0
Contraction scour (ft)	0.0
Local scour (ft)	2.8
Bend Scour[c] (ft)	2.4
Abutment Scour[d] (ft)	0.4
Total depth of scour[f] (ft)	5.8

Notes: a. 2080 100-year projected flow event
b. 2080 100-year projected flow event
c. Calculated using the 2-year flow event hydraulics.
d. Calculated by assuming channel migration to the abutment and main channel scour condition.
e. Total scour includes abutment scour component but not contraction scour component as NCHRP 24-20 abutment scour approach includes contraction scour (FHWA 2012).
f. Depth of scour to be applied to thalweg elevation

8 Scour Countermeasures

Since UNT Dogfish Creek through the project area is not considered to have low risk for lateral migration, the project crossing structure must be designed as if stream migration could occur. Therefore, any scour countermeasure should be designed to protect the roadway embankment in the event of channel migration, and any scour protection counter measure such as buried rock revetment or walls should be installed below the calculated total scour depth below the channel thalweg shown in Table 20. Furthermore, scour countermeasures shall not encroach within the minimum hydraulic opening. Specific structural elements such as retaining walls or wing walls have not been designed and are pending a geotechnical report and structural design. Figure 78 and Figure 79 illustrate a typical section and plan view layout for conceptual design of buried rock scour countermeasures.

Approximate lateral extents of proposed buried scour countermeasures are 70 feet, which is approximately 34 feet larger than the minimum hydraulic opening (Figure 78). Approximate longitudinal extents are about 144 feet, which extends 37 feet beyond the upstream/north ROW and 45 feet beyond the downstream/south ROW (Figure 79). The design is meant to facilitate discussions regarding TCE, ROW, SFZ, etc. and is not meant to be taken as a final recommendation.

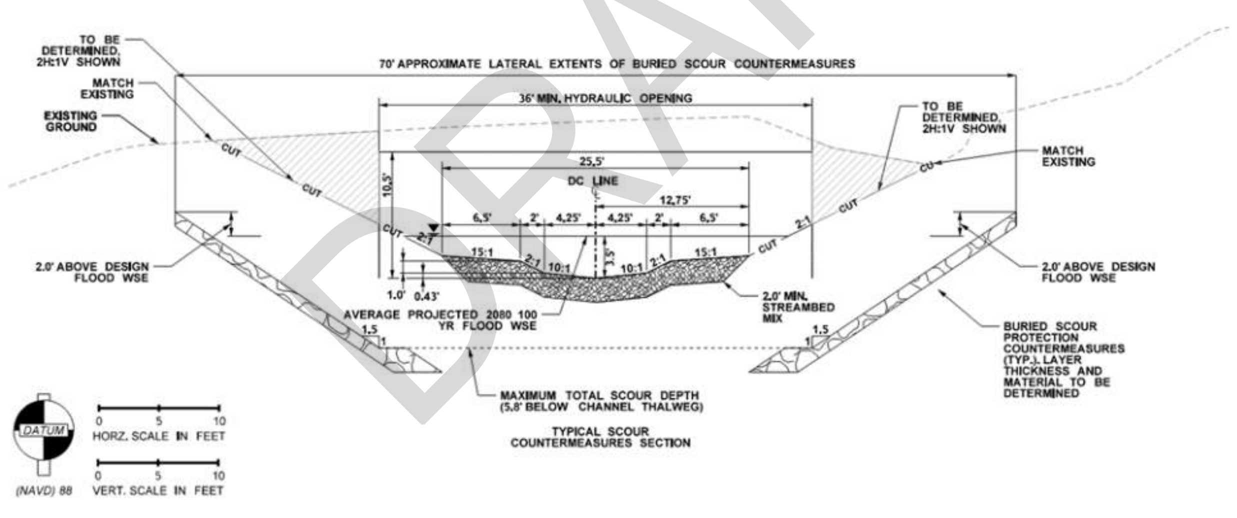

Figure 78: Typical channel design section through proposed crossing showing buried scour countermeasures

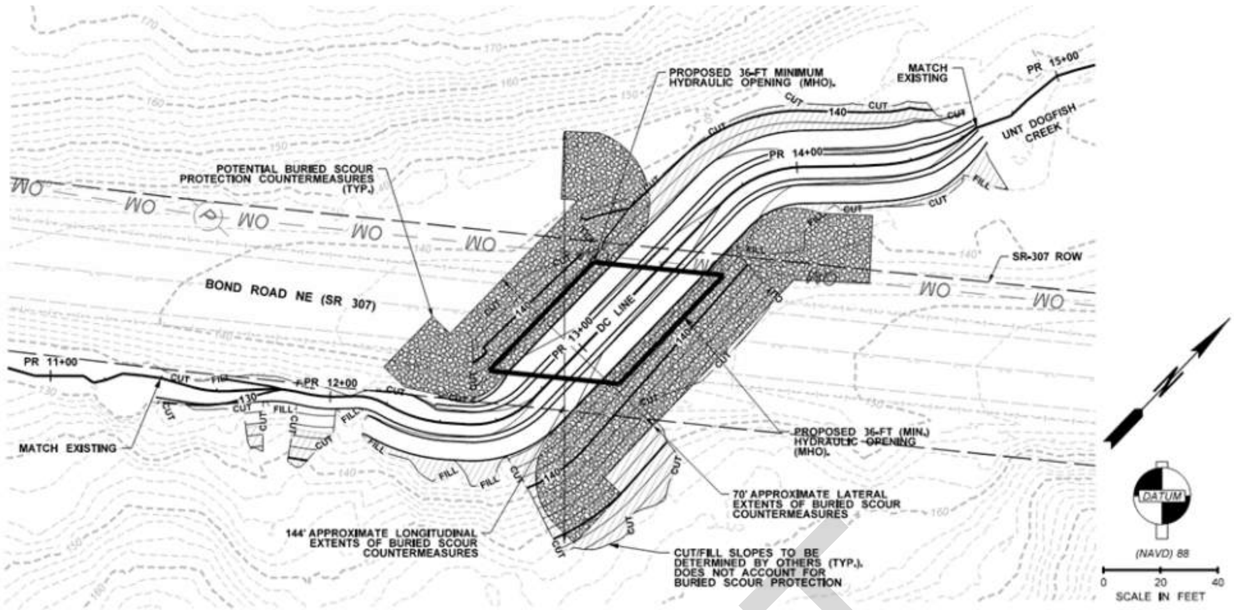

Figure 79: Conceptual layout for buried scour countermeasures

9 Summary

Table 21 presents a summary of the results of this PHD Report.

Table 21: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	2,734 LF	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	12.4 ft	2.7.2 Channel Geometry
	Concurrence BFW	12.4 ft	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	41.7 ft	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	DS: 1.3 US:4.9	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	219 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr flow	353 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr used for design	Yes	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	No	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	-0.1%	2.6.2 Existing Conditions
	Reference reach	1.8%	2.7.2 Channel Geometry
	Proposed	2.1%	4.1.3 Channel Gradient
Hydraulic width	Existing	4 ft	4.2.2 Hydraulic Width
	Proposed	36 ft	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	3 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080 100 yr	2080 100 yr	4.2.3 Vertical Clearance
	Maintenance clearance	Recommended 6 ft	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	70 ft	2.6.2 Existing Conditions
	Proposed	53 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	No	4.2.6 Structure Type
	Type	TBD	4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	No	4.3.1 Bed Material
Channel complexity	LWM for bank stability	No	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	No	4.3.2 Channel Complexity

Stream crossing category	Element	Value	Report location
	Meander bars	2	4.3.2 Channel Complexity
	Boulder clusters	0	4.3.2 Channel Complexity
	Coarse bands	0	4.3.2 Channel Complexity
	Mobile wood	Yes (Meander Bars)	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	No	2.7.5 Channel Migration
	Floodplain changes?	Yes	6 Floodplain Evaluation
Scour	Analysis	See link	7 Preliminary Scour Analysis
	Scour countermeasures	Determined at FHD	8 Scour Countermeasures
Channel degradation	Potential?	0 to 3 ft	7.2 Long-term Degradation of the Channel Bed
Channel degradation	Allowed?	yes	7.2 Long-term Degradation of the Channel Bed

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Appendices

Appendix A: FEMA Floodplain Map

National Flood Hazard Layer FIRMette

FEMA

122°37'36"W 47°45'48"N

0 250 500 1,000 1,500 2,000 Feet

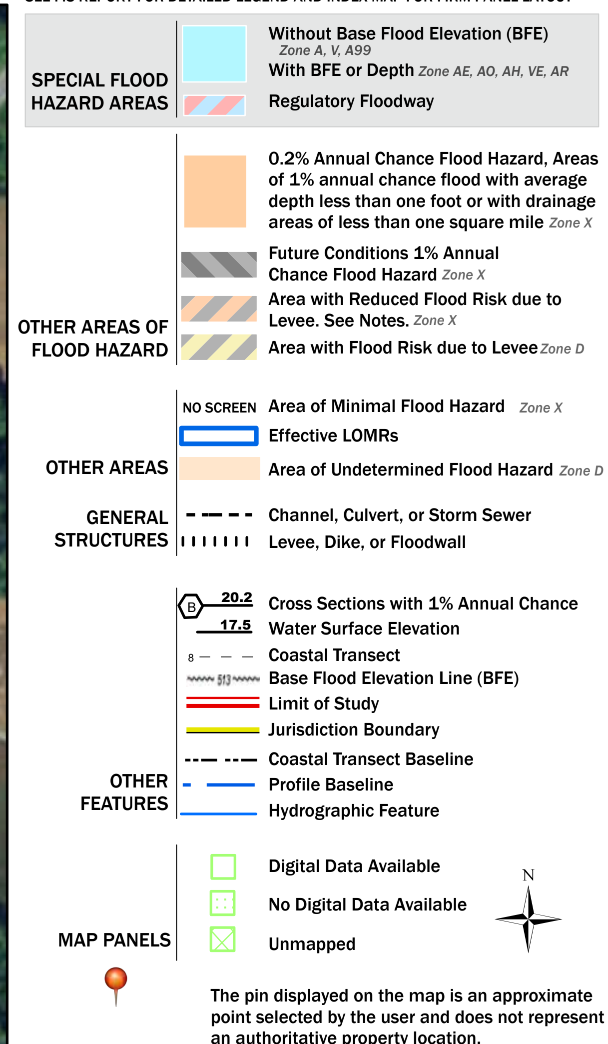
1:6,000

122°36'59"W 47°45'24"N

Basemap: USGS National Map: Orthoimagery: Data refreshed October, 2020

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT



This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 9/21/2022 at 2:38 PM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

Appendix B: Hydraulic Field Report Form

Section	Hydraulics Field Report	Project Number: Crossing 991999
	Project Name: NE Dogfish Creek Fish Passage Barrier Correction	Date: 12/10/2021
	Project Office:	Time of Arrival: 11:45 a.m.
	Stream Name: NE Dogfish Creek	Time of Departure: 4:30 p.m.
WDFW ID Number: 991999	Tributary to: Dogfish Creek	Weather: Cloudy
State Route/MP: SR 307 / 1.34	Township/Range/Section/ ¼ Section: T26N/R01E/S12	Prepared By: D. Fitzpatrick, A. Wright, M. Troost, K. Hyman-Rabeler Reviewed by: D. Eggers (12/15)
County: Kitsap	Purpose of Site Visit: Purpose of Site Visit: Assess crossing 991999	WRIA: 15

Meeting Location:
North of the intersection of Foss Rd NE and Bond Rd NE

Attendance List:

Name	Organization	Role
Adam Wright	GeoEngineers, Inc.	Fish Biologist
Dan Eggers	GeoEngineers, Inc.	Water Resources Engineer
Devan Fitzpatrick	GeoEngineers, Inc.	Staff Water Resources Engineer
Minda Troost	GeoEngineers, Inc.	Fluvial Geomorphologist
Katrina Hyman- Rabeler	GeoEngineers, Inc.	Staff Water Resources Engineer

The NE Dogfish Creek crossing 991999 on SR 307 has been identified as a fish passage barrier by the Washington Department of Fish and Wildlife (WDFW). GeoEngineers, Inc. (GeoEngineers) is working in conjunction with the Olympic Region General Engineering Consultant (Y-12554) team and Washington State Department of Transportation (WSDOT) to complete a preliminary hydraulic design with recommendations to develop a fish passable crossing. This hydraulics field report documents the existing geomorphic, biologic and hydraulic conditions of crossings 991999 observed by GeoEngineers on December 10th, 2021.

The GeoEngineers team met just north of the intersection of Foss Rd NE and SR 307 (Bond Rd NE) and conducted a pre-activity safety meeting. Following completion of the pre-activity safety meeting the team proceeded to conduct the site assessment from upstream to downstream. The project team accessed the upstream reach by walking southwest for approximately 600 feet along the SR 307 north road shoulder from the meeting location to a gravel driveway. The upstream reach was accessed by walking down the roadway embankment of the gravel driveway. The project team walked downstream through the upstream reach to the inlet of crossing 991999. The 991999-culvert outlet and downstream channel were accessed by crossing SR 307 and walking down the south SR 307 roadway embankment.

General Site Description:

Crossing 991999 is a 4-foot-diameter, round, corrugated metal culvert that conveys NE Dogfish Creek southeast under SR 307 at milepost 1.34 (Figure 1 and Figure 2). The immediate project vicinity is mainly forested within rural development. It is flanked by local roadways, and SR 307. The crossing and the downstream reach are located on WSDOT right-of-way (ROW), while the upstream reach is located on private property. Based on field observations and review of maps, the crossing is approximately 70 feet long.

Upstream of crossing 991999, NE Dogfish Creek flows southwest through a forested area towards the crossing inlet. Just upstream of the crossing the creek is confined between the SR 307 roadway embankment on the left bank and an abandoned roadway on the right bank. The abandoned roadway forces the stream to turn approximately 90 degrees into the 991999-culvert inlet. The SR 307 roadway embankment on the left bank consists of riprap and some large toe logs that appear to be placed. Downstream of the crossing 991999 outlet, NE Dogfish Creek flows southeast into a large pool before quickly turning southwest, flowing parallel to the SR 307 roadway embankment.

Bankfull Width:

The field team collected a total of six bankfull width (BFW) measurements, three upstream of crossing 991999 in the reference reach and three downstream of crossing 991999. The average BFW in the reference reach is 10.9 feet. All collected BFW measurements are shown in Table 1 below. Upstream BFW measurement locations are shown in Figure 3 through Figure 5 and downstream BFW measurement locations are shown in Figure 6 through Figure 8.

Table 1. Bankfull Width Measurements

BFW #	Approximate Distance from Crossing (feet)[2]	Bankfull Width (feet)	Source/Date
1	283[1]	10.6	GeoEngineers (December 2021)
2	204[1]	11.9	GeoEngineers (December 2021)
3	92[1]	10.2	GeoEngineers (December 2021)
4	231	11.4	GeoEngineers (December 2021)
5	279	11.0	GeoEngineers (December 2021)
6	300	9.2	GeoEngineers (December 2021)

Notes:
[1]Bankfull width measurements taken within the reference reach.
[2]Approximate distances are measured from the culvert inlet and outlet for the upstream and downstream reach respectively

Reference Reach:

A reference reach was established between approximately 80 feet and 330 feet upstream of the culvert inlet.
The reference reach location appeared to be outside of the influence of the culvert, away from the road prisms and approximately at the location where the stream transitions to an unconfined condition. The reference reach started at a riffle upstream of a small woody material jam (Figure 9). The terminus of the reference reach was at a large channel spanning tree where the channel transitioned to confined conditions (Figure 10). The upstream and downstream gradients are similar (Figure 11) but the upstream reference reach is generally unconfined, contains some sinuosity, has floodplain areas and several large woody material (LWM) accumulations with steps and pools and is generally more reflective of natural channel processes.

The 250-foot-long reference reach contained representative stream structures with a pool-riffle morphology and several wood-forced steps. Two full channel-spanning multi-log jam structures were observed engaging with the channel within the reference reach at approximately 150 feet and 235 feet upstream of the culvert. Additional pieces of LWM and mobile woody material were present throughout the reach contributing to the development of diverse micro habitats and in-channel complexity. LWM locations in the reference reach have been recorded for use in determination of Manning's roughness coefficients for hydraulic modeling.

Channel banks in the reference reach were generally 1 to 2 feet high. The floodplains were well developed with some mature vegetation and dense shrubs. The banks were primarily vegetated with salmonberry (*Rubus spectabilis*) youth-on-age (*Tolmiea menziesii*), sword fern (*Polystichum munitum*), and buttercup (*Ranunculus repens*).

The channel substrate consisted predominately of coarse gravel, sand, and some small cobbles. Three Wolman pebble counts were conducted by GeoEngineers field staff within the reference reach to calculate substrate gradation which is included in Table 2. In addition to the pebble counts and BFW measurements, the GeoEngineers field staff collected cross section data within the reference reach approximately 263 feet upstream of the culvert inlet.

The downstream reach is highly confined and channelized by the construction of SR 307. It is not representative of natural channel conditions and is not a suitable reference reach.

Data Collection:

All GeoEngineers field staff were involved in the data collection. Data collected include:

- BFW measurements
- General site observations
- Wolman pebble counts
- Manning's roughness observations (vegetation, large woody material, bed morphology, sediment, etc.)
- Large woody material checklist
- Project complexity checklist
- Cross section information using auto level

The upstream channel assessment extended approximately 330 feet from the inlet of crossing 991999 ending at a large channel spanning log. The channel upstream of the large channel spanning log appeared to be of a similar bankfull width but had less influence from instream wood. The downstream channel assessment extended approximately 400 feet from the culvert outlet to the location of a large woody material (LWM) jam that may be blocking fish passage.

Observations:

Crossing 991999

Crossing 991999 conveys NE Dogfish Creek under SR 307. The crossing consists of a 4-foot-diameter round corrugated metal culvert (Figure 1 and Figure 2). Upstream of the 991999 culvert inlet NE Dogfish Creek flows southwest before reaching the steep embankment of an abandoned roadway that forces flow to take a 90° turn southeast into the culvert inlet. The culvert inlet is partially blocked by a buildup of LWM and riprap (Figure 1) creating a low water surface drop into the pipe that is visible looking up from the outlet. A 2.5-foot-long concrete headwall extends from the right side of the culvert inlet along the SR 307 roadway embankment.

The culvert outlet has no wingwalls or a headwall (Figure 2). Flow exits the 991999-culvert outlet flowing to the southeast and forms an approximately 20-foot-wide pool before turning 90° to flow southwest along SR 307 (Figure 22). The outlet of crossing 991999 was perched above the channel with an approximately 0.8-foot invert to bed drop. The pool at the outlet had a maximum depth of approximately 3 feet at the time of the site assessment. No sediment was observed in the culvert inlet or outlet during the site assessment. The culvert diameter, lengths, and slope will be verified from WSDOT survey at a future date.

Geomorphology

Upstream Conditions

The first 400 feet of NE Dogfish Creek upstream of crossing 991999 is slightly sinuous within a valley bottom that ranges from 10 to 80 feet wide. The creek is constrained by a mix of natural topography and two roads on either side of the creek. An old, abandoned roadway follows the topography on the northwest side of the creek and SR 307 follows the left valley wall for the first 100 feet upstream on the southeast side of the creek. The two roadway prisms come together at the culvert and confine the creek to an approximately 10-foot-wide valley bottom that is occupied by the entirety of the creek. The left bank is coincident with the SR 307 road embankment with large riprap and or stacked toe logs (Figure 12) to help protect it. The right bank was not protected, consisting of sand and gravel that appeared to be fill of the abandoned roadway. The two roads begin to diverge approximately 50 feet upstream of the inlet and the creek begins to transition to an unconfined condition with floodplains. From about 100 feet to 250 feet upstream of the culvert the stream is unconfined. At about 250 feet upstream of the inlet it begins to transition back toward a relatively more confined condition.

Banks were generally 1 to 2 feet high ranging from near vertical to 2H:1V (Figure 13). Floodplains were well developed with some mature cedar (*Thuja plicata*) and alder (*Alnus rubra*) trees but mainly supported dense salmonberry with some vine maple (*Acer circinatum*) and red elderberry (*Sambucus racemosa*) (Figure 13).

The bedform was pool-riffle with several long glides (Figure 13) and several forced wood steps from 100 to 130 feet apart (see Large Woody Material section below). Glides gave the appearance of plane bed structure with some embedment up to 30%. Steps were commonly a series of several drops over LWM that caused approximately a total of 1 foot drop in water surface at each location. Deposition of gravel was associated either upstream due to backwater or downstream in the hydraulic shadow of the LWM (Figure 14). Deposition was also observed upstream of the culvert inlet (Figure 15) within approximately the first 50 feet of stream upstream from the inlet where the stream is highly confined. It appears that deposition in the middle of the channel has likely forced flow to the margins. The right bank is not armored and lateral erosion in the form of undercut banks was observed (Figure 16). No incision was observed in the assessed reach upstream of the crossing.

Downstream Conditions
NE Dogfish Creek downstream of the 991999 crossing was highly confined between the valley wall on the left bank and the SR 307 road embankment on the right (Figure 17). The valley walls commonly extended down to the creek and were coincident with the stream banks. There were several wider areas with gravel bars but no developed floodplains. The creek has no sinuosity in the assessed reach downstream of the outlet because it flows along the road embankment.

Bedform was pool-riffle with occasional woody material in the channel that forced small pools (Figure 19). Larger rocks also caused minor vertical scour forming small pools but no lateral erosion was observed. A single series of three steps formed by angular cobbles and boulders, giving the steps an artificial appearance, was observed about 60 feet downstream of the outlet (Figure 20). The total drop is approximately 1 to 1.5 feet.

Approximately 330 feet downstream of the outlet is a wood jam that is wedged between the valley walls and roadway prism forming an approximate 4-foot drop in the water surface (Figure 21). Downstream of the drop, scour along the left bank/valley wall due to another log in the channel was observed.

Aquatic Habitat Type and Location

Upstream Conditions
The upstream reach of NE Dogfish Creek provides high-quality fish habitat consisting of ample amounts of wood, deep pools, spawning gravel and occasional overbank floodplain areas that appear to be active at higher flows. Fish habitat within the assessed reach appeared suitable for spawning with plentiful patches of spawning gravels. Spawning gravels were available throughout numerous riffles in the reach. Some gravel bars may be suitable for steelhead and cutthroat spawning in the spring when flows are higher (Figure 4). Wood in the channel contributed to channel complexity and a large diversity of micro habitats with variations of in-channel velocities and water depths, providing diverse rearing habitats for juvenile fish (Figure 19). Large woody material jams led to the development of several deep pools with instream cover suitable for adult holding during migration and spawning in addition to use by juvenile or resident specimen (Figure 14). The deep pools formed from instream wood were frequently in proximity to potential spawning habitat. At several locations the banks were undercut providing additional instream cover. The reach has good overbank and canopy cover from surrounding dense vegetation providing food inputs and shade during summer months.

Downstream Conditions
The reach downstream of crossing 991999 provides lower-quality adult and juvenile salmonid habitat due mainly to the more continuous, direct impacts associated with its proximity to the highway (Figure 18). The downstream reach has less woody material and no sinuosity in the channel, and consequently less instream complexity. Submerged cover was generally limited to larger boulders, apparently mobilized from along the right bank, or smaller pieces of mobile wood. Proximity parallel to the roadway toe also limits vegetation cover and floodplain refuge along the right bank; similar conditions were observed along the left bank although this feature was not obviously manipulated. There were occasional patches of spawning gravels in the downstream reach, often located at the crest of riffles.
Approximately 330 feet downstream there was an accumulation of LWM in the channel consisting of several large logs and a large quantity of smaller woody debris (Figure 21). The blockage has an approximately 5-foot water surface elevation drop and likely blocks fish passage upstream in its current configuration.

Large Woody Material Location and Quantity

Upstream Conditions
Ample woody material was present upstream of crossing 991999. Woody material in the upstream reach engaging with flow consisted of both smaller mobile woody material and larger key pieces. Larger key pieces were observed racking smaller mobile woody material at several locations in the upstream reach leading to the development of LWM channel spanning jams and downstream scour pools. The woody material present in the upstream reach contributed to the development of channel complexity and a large diversity of micro habitats.

The culvert inlet was partially obstructed by a buildup of LWM between 13 and 18 inches in diameter (Figure 1). Due to the accumulation of woody material upstream of the culvert inlet, transport of mobile woody material may be a consideration in determination of the hydraulic opening. Two stacked toe logs approximately 9 inches and 12 inches in diameter, were observed on the left bank at the toe of the SR 307 roadway embankment approximately 26 to 60 feet upstream of the culvert inlet. The logs appeared to be purposefully placed at the toe along with several pieces of large riprap.

A small woody material jam was located approximately 45 feet upstream of the culvert inlet consisting of mobile woody material racked on one channel spanning log approximately 8 inches in diameter and two additional logs 10 -12 inches in diameter extending into the channel from the banks (Figure 23). A single 16-inch channel spanning log partially buried in the channel bed was observed approximately 58 feet upstream of the culvert creating a forced riffle pool (Figure 24). A second LWM jam was observed approximately 150-feet upstream of the culvert inlet consisting of several key members and racking material. The jam appears to have led to the development of a high flow side channel on the left bank (Figure 25 and Figure 26). One-hundred and eighty-two feet upstream of the culvert a 4.5-inch diameter wood piece was observed spanning the channel (Figure 27). A third large wood jam was observed 235 feet upstream of the culvert (Figure 28). The jam consisted of a 16-inch diameter root wad with additional racking members. The structure created a scour pool with a water depth of 2.2 feet. Approximately 330-feet upstream of the culvert was an immobile channel spanning log approximately 18 inches in diameter wedged between two trees on the right bank (Figure 10). The large key piece is potentially outside of the 100-year flood water surface elevation and had an average low chord of approximately 3 feet above the channel thalweg.

Downstream Conditions
Less woody material was observed downstream of crossing 991999 compared to upstream. Woody material was observed partially obstructing the culvert outlet and engaging with flows in the large pool at the culvert outlet (Figure 29). Additional LWM was observed extending into the channel from both banks 108 to 119 feet downstream of the culvert outlet ranging from 9 inches to 12 inches in diameter (Figure 30). There is limited potential for additional recruitment of woody material from the right bank due to the proximity of the channel to the roadway embankment.

Vegetation

Upstream Conditions
Upstream of the 991999 crossing, NE Dogfish Creek flows through a forested area with an active floodplain. Channel banks are vegetated with salmonberry, youth-on-age, sword fern, and buttercup. The overstory predominately consists of red alder, big leaf maple (*Acer Macrophyllum*) and western red cedar. One small path of invasive archangel (*Lamiastrum galeobdolon*) was found along the stream bank. Overhead cover in the reference reach is estimated to be 75 percent.

Downstream Conditions
Downstream of the 991999 crossing, NE Dogfish Creek flows adjacent to the SR 307 road prism through a forested area. Right bank vegetation is limited due to the SR 307 road embankment. The left channel banks are vegetated with salmonberry, youth-on-age and sword fern. The overstory predominately consists of red alder, western red cedar, and hemlock (*Tsuga Heterophylla*).

Pebble Counts:

A total of six Wolman pebble counts were collected during the assessment. Three pebble counts were collected upstream and three downstream of the 991999 culvert. Upstream pebble counts, PC1, PC2 and PC3, were at 260, 225 and 130 feet, respectively, upstream of the 991999-crossing inlet (Figure 31 through Figure 33). Downstream pebble counts, PC4, PC5 and PC6, were at 70, 180 and 274 feet, respectively, downstream of the 991995-crossing outlet (Figure 34 through Figure 36). Samples were collected at 10 transects along riffles for each pebble count. No boulders were observed in the upstream reference reach or downstream of the crossing. Some boulders were observed along the right bank downstream of the culvert outlet, but were angular and presumed to be associated with the SR 307 roadway embankment.

Sediment upstream of crossing 991999 was comprised mainly of gravels with smaller portions of sands and small cobbles. The sediment downstream of crossing 991999 was slightly larger than upstream.

Table 2. Sediment Sizes

Pebble Count	Upstream (reference reach)			Downstream		
Diameter Percentile	PC1 (in)	PC2 (in)	PC3 (in)	PC4 (in)	PC5 (in)	PC6 (in)
D_{100}	3.5 – 5.0			5.0 -7.1		
D_{84}	1.8	1.7	1.9	2.2	2.4	2.0
D_{50}	1.0	0.8	1.0	1.1	1.5	1.0
D_{16}	0.5	0.4	0.4	0.5	0.7	0.4

Photos:


Figure 1: Crossing 91999 inlet with woody debris (arrow shows flow direction).

Figure 2: Crossing 91999 outlet (arrow shows flow direction).

Figure 3. Location of BFW#1.

Figure 4. Location of BFW#2.

Figure 5. Location of BFW #3.

Figure 6. Location of BFW#4.


Figure 7. Location of BFW#5.

Figure 8. Location of BFW#6.

Figure 9. Start of reference reach 80 FT upstream of inlet looking upstream (arrow shows flow direction).

Figure 10: End of reference reach 330FT upstream of inlet at a channel spanning log.

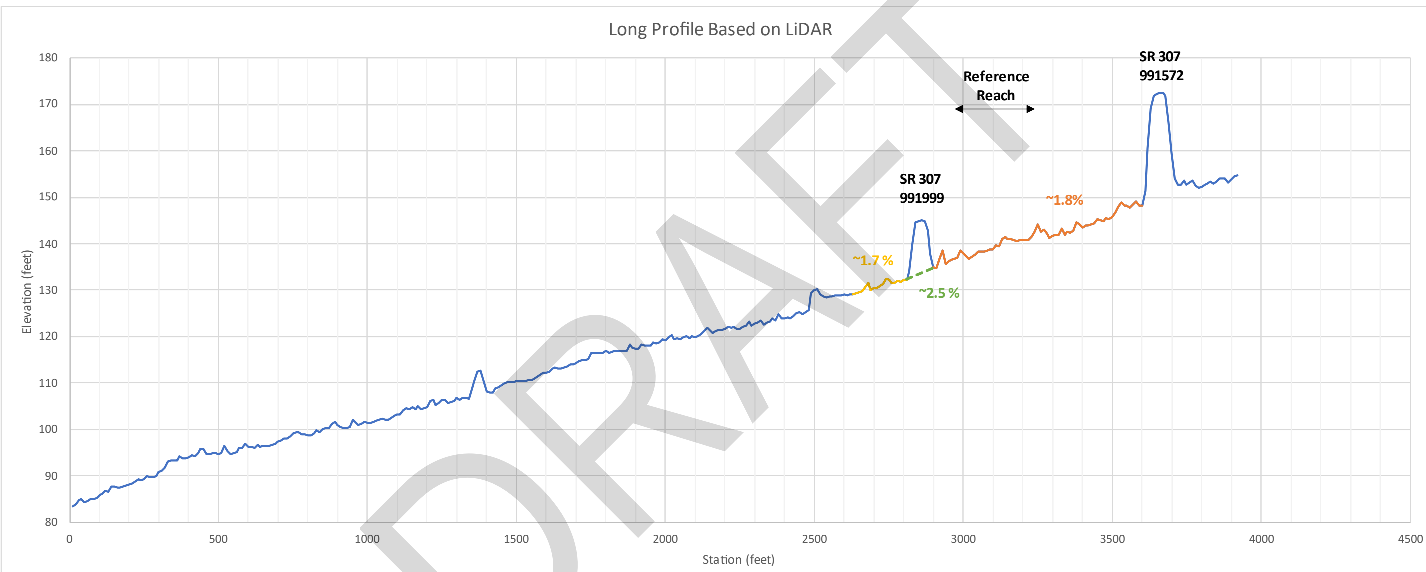


Figure 11: Long profile from LiDAR.

Figure 12: Stacked toe logs along left bank road embankment. Arrow indicates flow direction. Notice cables in lower middle right of photo. Large riprap sits just downstream of the end of the logs.

Figure 13: Vertical and undercut left bank. 2H:1V on right bank. Some large trees and brush on floodplains. Long glide in middle of photo gives appearance of plane bed structure.


Figure 14: Gravel bar built up in hydraulic shadow of large rootwad that is just out of the photo frame left. Gravel bar splits flow.


Figure 15: Gravel accumulation upstream of the culvert. Culvert is lower left.


Figure 16: undercut bank upstream of culvert.


Figure 17: Highly confined creek downstream of culvert, valley wall to the left, road embankment on the right.

Figure 18: Highly confined conditions continue downstream of culvert, valley wall to the left, road embankment on the right, with occasional large boulders interacting with the channel along the right bank.


Figure 19: Occasional woody material forcing small pools.

Figure 20: Series of rock steps that are most likely artificial.

Figure 21: Tangle of large wood, potentially forming a fish passage barrier. Arrows indicate direction of flow.

Figure 22. Large pool near culvert outlet due to LWM.


Figure 23: Looking downstream at a large woody material complex approximately 45 feet upstream of the crossing.


Figure 24: Looking upstream at buried LWM (16" diameter) approximately 58 feet upstream of the culvert.


Figure 25: Channel spanning LWM in the high flow channel just upstream of where the high flow channel meets the main channel 129 feet upstream of the culvert.

Figure 26: Looking downstream at a channel spanning log and other woody material in the main channel just upstream of where the high flow channel meets the main channel 129 feet upstream of the culvert.

Figure 27: Looking upstream at a channel spanning log 182 feet upstream of the culvert.

Figure 28: Looking upstream at a root wad engaging with flow approximately 247 feet upstream of the culvert inlet.


Figure 29: Woody material located just downstream of the culvert outlet.

Figure 30: Looking downstream at woody material extending into the channel 108 to 119 feet downstream of the culvert outlet.

Figure 31. PC#1.

Figure 32. PC #2.

Figure 33. PC#3.

Figure 34. PC #4.


Figure 35. PC#5.

Figure 36. PC#6.

Samples:	
Work within the wetted perimeter may only occur during the time periods authorized in the APP ID 21036 entitled "Allowable Freshwater Work Times May 2018". Work outside of the wetted perimeter may occur year-round. APPS website: https://www.govonlinesaas.com/WA/WDFW/Public/Client/WA_WDFW/Shared/Pages/Main/Login.aspx	
Were any sample(s) collected from below the OHWM?	*No ☐ If no, then stop here.* *Yes ☐ If yes, then fill out the proceeding section for each sample.*

Sample #:	Work Start:	Work End:	Latitude:	Longitude:

Summary/description of location:
Summarize/describe the sample location.
Description of work below the OHWL:
Describe the work below the OHWL, including equipment used and quantity of sediment sampled.
Description of problems encountered:
Describe any problems encountered, such as provision violations, notification, corrective action, and impacts to fish life and water quality from problems that arose.

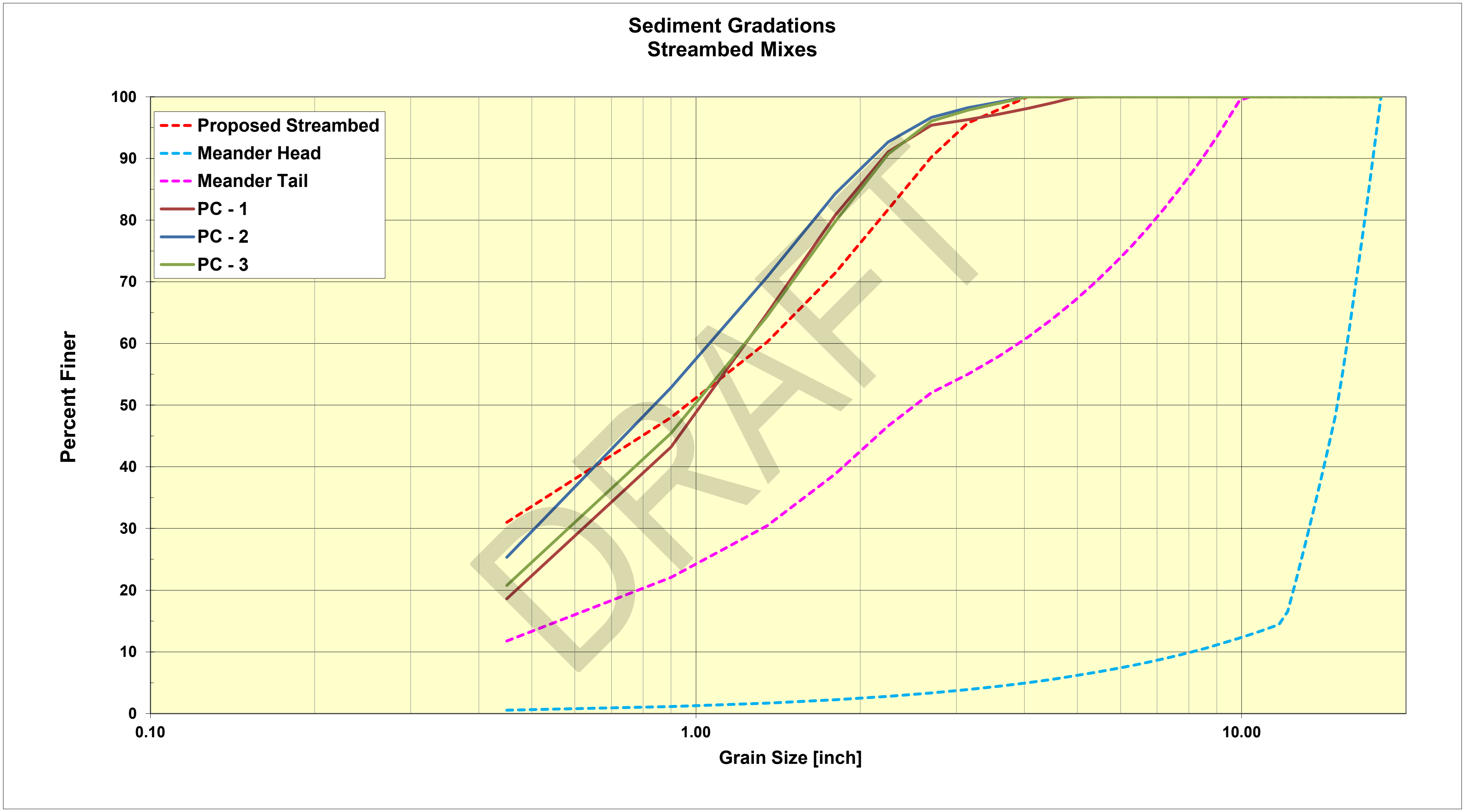
# Concurrence Meeting	Date:	Time of Arrival:
Prepared By:	Weather:	Time of Departure:

Attendance List:

Name	**Organization**	**Role**

Bankfull Width:
Summarize on-site discussion, describe measurements, and concurrence or decisions made that help to inform the design.
Reference Reach:
Summarize on site discussion, concurrence and/or appropriateness of selected reference reach.
Observations:
Summarize on site discussions, any perceived/known project constraints, or other details that help to inform the design.
Photos:
Any relevant photographs placed here with descriptions.

Appendix C: Streambed Material Sizing Calculations


Sediment Gradations
Streambed Mixes
Proposed Streambed
Meander Head
Meander Tail
PC - 1
PC - 2
PC - 3
Percent Finer
Grain Size [inch]
0
10
20
30
40
50
60
70
80
90
100
0.10
1.00
10.00
DRAFT

Design Gradation: Critical Shear				
Location:	Proposed Channel			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.33	0.19	0.08	0.01
in	4.0	2.3	0.9	0.1
mm	102	59	23.8	1.6

Existing Gradation				
Location:	Reference Reach - Upstream Average			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.34	0.15	0.08	0.03
in	4.0	1.8	0.9	0.4
mm	102.7	45.7	23.6	10.5

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

	Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
	36.0	914									100	100.0
	32.0	813									50	100.0
	28.0	711								100		100.0
	23.0	584								50		100.0
	18.0	457							100			100.0
	15.0	381							50			100.0
	12.0	305						100				100.0
	10.0	254					100	80				100.0
	8.0	203				100	80	68				100.0
	6.0	152			100	80	68	57				100.0
	5.0	127			80	68	57	45				100.0
	4.0	102		100	71	57	45	39				100.0
	3.0	76.2		80	63	45	38	34				95.0
	2.5	63.5	100	65	54	37	32	28				91.3
	2.0	50.8	80	50	45	29	25	22				72.5
	1.5	38.1	73	35	32	21	18	16				63.1
	1.0	25.4	65	20	18	13	12	11				53.8
	0.75	19.1	50	5	5	5	5	5				38.8
No. 4	0.19	4.75	35									26.3
No. 40	0.02	0.425	16									12.0
No. 200	0.00	0.0750	7									5.3
	% per category		75	25	0	0	0	0	0	0	0	--> 100%
	% Cobble & Sediment											100.0%

References:

United States Forest Service - Stream Simulation 2008

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in	Meets Criteria
Uniform bed material (Di < 20-30 times D50)	Uniform
Slopes less than 5%	Yes, proposed slope is 2.0%
Sand/gravel streams with high relative submergence	Yes
2yr-depth	2.00 ft
Relative Submergence:	0.47
γ_s	165 specific weight of sediment particle (lb/ft^3)
γ	62.4 specific weight of water (1b/ft^3)
τ_{D50}	0.047 dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed
D50 in mm	23.8
Link to Model Results:	Refer to Table 18 in PHD

Flow	2-YR	100-YR	2080 100-YR	500-YR
Average Modeled Shear Stress (lb/ft^2)	1.20	2.50	3.00	2.60
τ_{ci}				
1.13	Motion	Motion	Motion	Motion
1.09	Motion	Motion	Motion	Motion
1.04	Motion	Motion	Motion	Motion
0.98	Motion	Motion	Motion	Motion
0.91	Motion	Motion	Motion	Motion
0.87	Motion	Motion	Motion	Motion
0.81	Motion	Motion	Motion	Motion
0.77	Motion	Motion	Motion	Motion
0.72	Motion	Motion	Motion	Motion
0.66	Motion	Motion	Motion	Motion
0.62	Motion	Motion	Motion	Motion
0.58	Motion	Motion	Motion	Motion
0.53	Motion	Motion	Motion	Motion
0.51	Motion	Motion	Motion	Motion
0.47	Motion	Motion	Motion	Motion
0.43	Motion	Motion	Motion	Motion
0.38	Motion	Motion	Motion	Motion
0.35	Motion	Motion	Motion	Motion

D16	0.1	in
D50	0.9	in
	0.078	ft
D84	2.3	in
D95	3.0	in
D100	4.0	in

Design Gradation: Critical Shear				
Location:	Meander Bar Head			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	1.50	1.42	1.25	1.08
in	18.0	17.0	15.0	13.0
mm	457	433	381.0	329.2

Existing Gradation				
Location:	Reference Reach - Upstream Average			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.34	0.15	0.08	0.03
in	4.0	1.8	0.9	0.4
mm	102.7	45.7	23.6	10.5

References:

United States Forest Service - Stream Simulation 2008

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in	Does Not Meet Criteria	
Uniform bed material (Di < 20-30 times D50)	Uniform	
Slopes less than 5%	Yes, proposed slope is 2.0%	
Sand/gravel streams with high relative submergence	Yes	
2yr-depth	2.00	ft
Relative Submergence:	7.50	
γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.054	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed
D50 in mm	381.0	
Link to Model Results:	Refer to Table 18 in PHD	

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

	Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
	36.0	914									100	100.0
	32.0	813									50	100.0
	28.0	711								100		100.0
	23.0	584								50		100.0
	18.0	457							100			100.0
	15.0	381							50			50.0
	12.0	305						100				0.0
	10.0	254					100	80				0.0
	8.0	203				100	80	68				0.0
	6.0	152			100	80	68	57				0.0
	5.0	127			80	68	57	45				0.0
	4.0	102		100	71	57	45	39				0.0
	3.0	76.2		80	63	45	38	34				0.0
	2.5	63.5	100	65	54	37	32	28				0.0
	2.0	50.8	80	50	45	29	25	22				0.0
	1.5	38.1	73	35	32	21	18	16				0.0
	1.0	25.4	65	20	18	13	12	11				0.0
	0.75	19.1	50	5	5	5	5	5				0.0
No. 4	0.19	4.75	35									0.0
No. 40	0.02	0.425	16									0.0
No. 200	0.00	0.0750	7									0.0
	% per category		0	0	0	0	0	0	100	0	0	--> 100%
	% Cobble & Sediment											0.0%

Flow	2-YR	100-YR	2080 100-YR	500-YR
Average Modeled Shear Stress (lb/ft^2)	1.20	2.50	3.00	2.60
τ_{ci}				
9.01	No Motion	No Motion	No Motion	No Motion
8.69	No Motion	No Motion	No Motion	No Motion
8.35	No Motion	No Motion	No Motion	No Motion
7.87	No Motion	No Motion	No Motion	No Motion
7.31	No Motion	No Motion	No Motion	No Motion
6.93	No Motion	No Motion	No Motion	No Motion
6.48	No Motion	No Motion	No Motion	No Motion
6.13	No Motion	No Motion	No Motion	No Motion
5.74	No Motion	No Motion	No Motion	No Motion
5.26	No Motion	No Motion	No Motion	No Motion
4.98	No Motion	No Motion	No Motion	No Motion
4.66	No Motion	No Motion	No Motion	No Motion
4.27	No Motion	No Motion	No Motion	No Motion
4.05	No Motion	No Motion	No Motion	No Motion
3.78	No Motion	No Motion	No Motion	No Motion
3.47	No Motion	No Motion	No Motion	No Motion
3.07	No Motion	No Motion	No Motion	No Motion
2.82	No Motion	No Motion	Motion	No Motion

D16	13.0	in
D50	15.0	in
	1.250	ft
D84	17.0	in
D95	17.7	in
D100	18.0	in

Design Gradation: Critical Shear				
Location:	Meander Bar Tail			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.83	0.63	0.20	0.05
in	10.0	7.5	2.4	0.6
mm	254	191	60.9	14.6

Existing Gradation				
Location:	Reference Reach - Upstream Average			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.34	0.15	0.08	0.03
in	4.0	1.8	0.9	0.4
mm	102.7	45.7	23.6	10.5

References:

United States Forest Service - Stream Simulation 2008

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in	Meets Criteria	
Uniform bed material (Di < 20-30 times D50)	Uniform	
Slopes less than 5%	Yes, proposed slope is 2.0%	
Sand/gravel streams with high relative submergence	Yes	
2yr-depth	2.00	ft
Relative Submergence:	1.20	
γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.050	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed
D50 in mm	60.9	
Link to Model Results:	Refer to Table 18 in PHD	

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

	Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}	τ_{ci}	Flow 2-YR	100-YR	2080 100-YR	500-YR
													Average Modeled Shear Stress (lb/ft^2)	1.20	2.50	3.00	2.60
	36.0	914									100	100.0	2.31	No Motion	Motion	Motion	Motion
	32.0	813									50	100.0	2.23	No Motion	Motion	Motion	Motion
	28.0	711								100		100.0	2.14	No Motion	Motion	Motion	Motion
	23.0	584								50		100.0	2.02	No Motion	Motion	Motion	Motion
	18.0	457							100			100.0	1.88	No Motion	Motion	Motion	Motion
	15.0	381							50			100.0	1.78	No Motion	Motion	Motion	Motion
	12.0	305						100				100.0	1.66	No Motion	Motion	Motion	Motion
	10.0	254					100	80				100.0	1.57	No Motion	Motion	Motion	Motion
	8.0	203				100	80	68				86.0	1.47	No Motion	Motion	Motion	Motion
	6.0	152			100	80	68	57				77.8	1.35	No Motion	Motion	Motion	Motion
	5.0	127			80	68	57	45				69.7	1.28	No Motion	Motion	Motion	Motion
	4.0	102		100	71	57	45	39				61.5	1.20	Motion	Motion	Motion	Motion
	3.0	76.2		80	63	45	38	34				56.8	1.10	Motion	Motion	Motion	Motion
	2.5	63.5	100	65	54	37	32	28				52.2	1.04	Motion	Motion	Motion	Motion
	2.0	50.8	80	50	45	29	25	22				41.5	0.97	Motion	Motion	Motion	Motion
	1.5	38.1	73	35	32	21	18	16				34.6	0.89	Motion	Motion	Motion	Motion
	1.0	25.4	65	20	18	13	12	11				27.7	0.79	Motion	Motion	Motion	Motion
	0.75	19.1	50	5	5	5	5	5				18.5	0.72	Motion	Motion	Motion	Motion
No. 4	0.19	4.75	35									10.5					
No. 40	0.02	0.425	16									4.8					
No. 200	0.00	0.0750	7									2.1					
	% per category		30	0	0	0	70	0	0	0	0	--> 100%					
	% Cobble & Sediment											100.0%					

D16	0.6	in
D50	2.4	in
	0.200	ft
D84	7.5	in
D95	9.3	in
D100	10.0	in

Large Rock Overtopping Flow Stability Analysis

Per WSDOT Meander Bar Guidance dated 4/12/2022

Structure Head:
Materials used in the design and subsequent construction of the head of the Meander Bars shall consist of large rock designed to be stable at the 100-year flow event. The stability analysis shall include overtopping rock features. (See 2012 Washington Department of Fish and Wildlife Stream Habitat Restoration Guidelines pgs T6-20 & 21.

Per 2012 WDFW Stream Habitat Guidelines page T6-21

Ishbash's equation:

$$D_{min} = V^2/\{1.479g[(SG_s - SG_w)/SG_w]\}$$

Dmin	**1.2473**	**(inches)**
Dmin	**0.1039**	**(feet) Minimum diameter stone necessary to withstand design velocity**
V	**3.3**	**Design velocity (use 100-year flow event) (ft/s)**
g	**32.2**	**Gravity (32.2 ft/s^2)**
SGs	**3.2**	**Specific Gravity of stone, varies between 2.2 to 3.2**
SGw	**1**	**Specific Gravity of water, 1.0**

Costa's 1983 equation

$$D_{min} = \left(V_{avg}/9.571\right)^{2.05}$$

Dmin	**1.3526**	**(inches)**
Dmin	**0.1127**	**(feet) Minimum diameter stone necessary to withstand design velocity**
Vavg	**3.3**	**Average velocity (use 100-year flow event) (ft/s)**

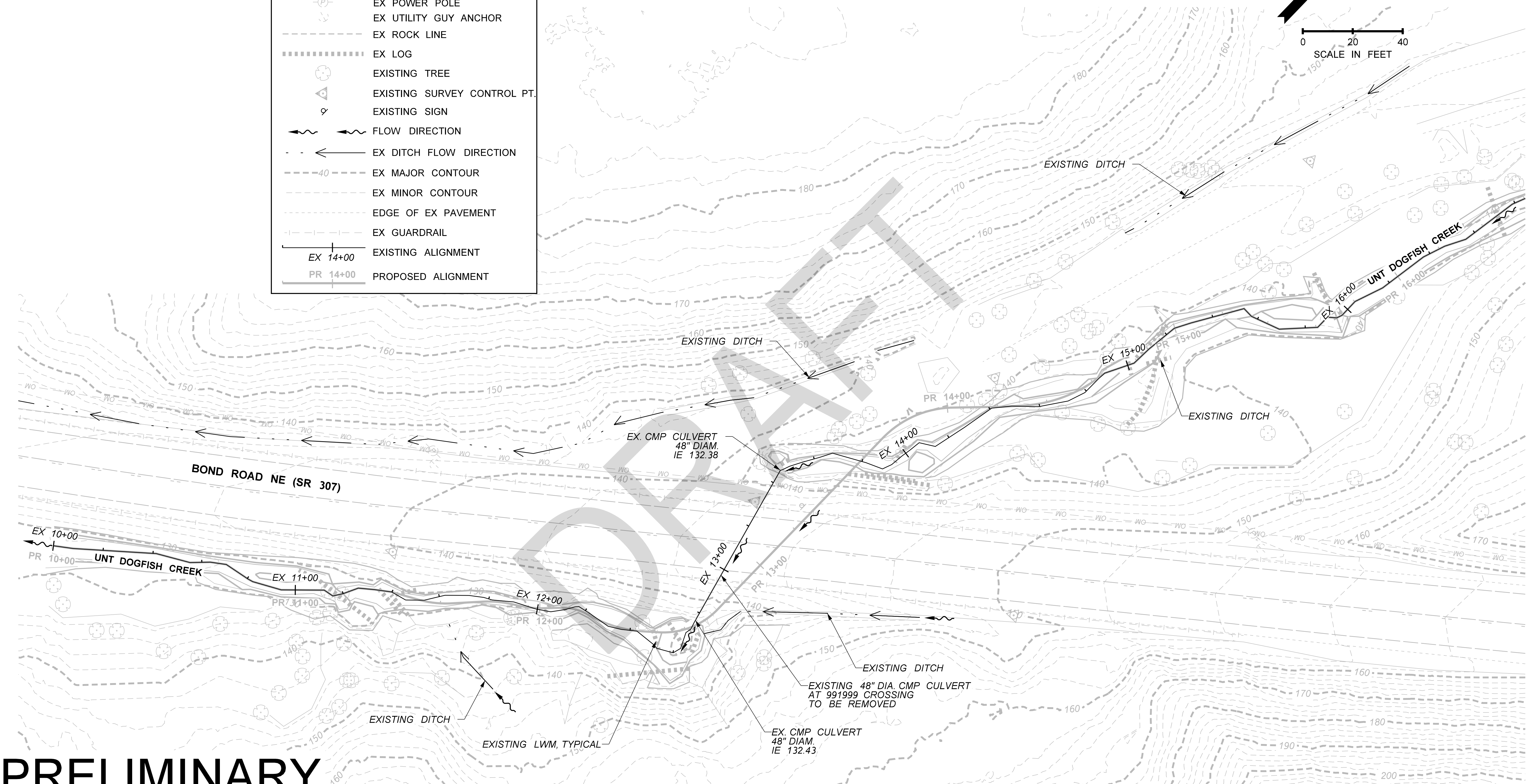
Appendix D: Stream Plan Sheets, Profile, Details

NOTES:

1. SITE SURVEY, STREAM GRADING AND EXISTING CONTOURS BASED ON SURVEY COMPLETED BY WSDOT IN FEBRUARY 2022 (NAVD 88).
2. HORIZONTAL DATUM: LOCAL PROJECT DATUM.

LEGEND

- EXISTING CULVERT
- EX RD MRK WHITE LINE
- EX RD MRK NO-PASS YELLOW LINE
- EX OVERHEAD UTILITIES
- EX POWER POLE
- EX UTILITY GUY ANCHOR
- EX ROCK LINE
- EX LOG
- EXISTING TREE
- EXISTING SURVEY CONTROL PT.
- EXISTING SIGN
- FLOW DIRECTION
- EX DITCH FLOW DIRECTION
- EX MAJOR CONTOUR
- EX MINOR CONTOUR
- EDGE OF EX PAVEMENT
- EX GUARDRAIL
- EX 14+00 EXISTING ALIGNMENT
- PR 14+00 PROPOSED ALIGNMENT



PRELIMINARY

NOT FOR CONSTRUCTION

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DESIGNED BY	A. MORTON			
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PROJ. ENGR.				
REGIONAL ADM.		REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 307
UNT DOGFISH CREEK
FISH BARRIER REMOVAL DESIGN

EXISTING STREAM PLAN

PLAN REF NO HY01

SHEET 1 OF 4 SHEETS

NOTES:

1. SITE SURVEY, STREAM GRADING AND EXISTING CONTOURS BASED ON SURVEY COMPLETED BY WSDOT IN FEBRUARY 2022 (NAVD 88)

2. HORIZONTAL DATUM: LOCAL PROJECT DATUM

3. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WALLS TO BE DETERMINED.

4. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE, TYPE, SIZE AND LOCATION.

5. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION BY OTHERS.

6. MEANDER BARS THROUGH CROSSING ARE TO BE COMPOSED OF COARSER MATERIAL THAN THE ADJACENT CHANNEL IN ACCORDANCE WITH WSDOT MEANDER BAR DESIGN GUIDANCE.

LEGEND

EXISTING CULVERT
EX RD MRK WHITE LINE
EX RD MRK NO-PASS YELLOW LINE
EX OVERHEAD UTILITIES
EX POWER POLE
EX UTILITY GUY ANCHOR
EX ROCK LINE
EX LOG
EXISTING TREE
EXISTING SURVEY CONTROL PT.
EXISTING SIGN
FLOW DIRECTION
EX DITCH FLOW DIRECTION
EX MAJOR CONTOUR
EX MINOR CONTOUR
EDGE OF EX PAVEMENT
EX GUARDRAIL

LEGEND

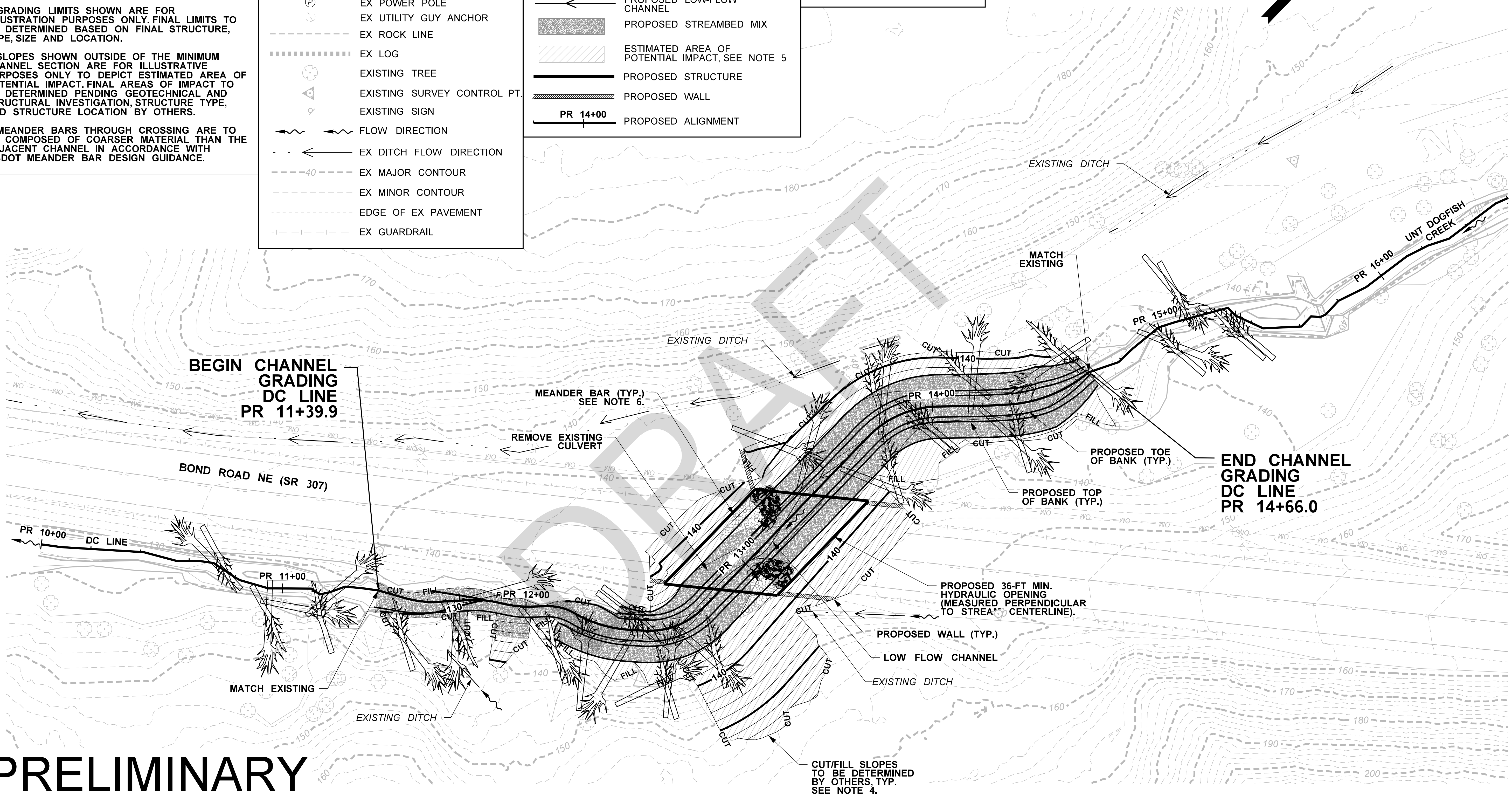
PROPOSED CUT LINE
PROPOSED MAJOR CONTOUR
PROPOSED MINOR CONTOUR
PROPOSED LOW-FLOW CHANNEL
PROPOSED STREAMBED MIX
ESTIMATED AREA OF POTENTIAL IMPACT, SEE NOTE 5
PROPOSED STRUCTURE
PROPOSED WALL
PROPOSED ALIGNMENT

LOG SCHEDULE

TYPE A LOG
TYPE B LOG

0 20 40
SCALE IN FEET

DATUM
(NAVD) 88



PRELIMINARY

NOT FOR CONSTRUCTION

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ENTERED BY	J. GERMAN		
CHECKED BY	D. EGGERS		
PROJ. ENGR.			
REGIONAL ADM.	REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

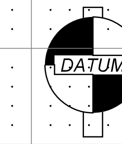
SR 307
UNT DOGFISH CREEK
FISH BARRIER REMOVAL DESIGN

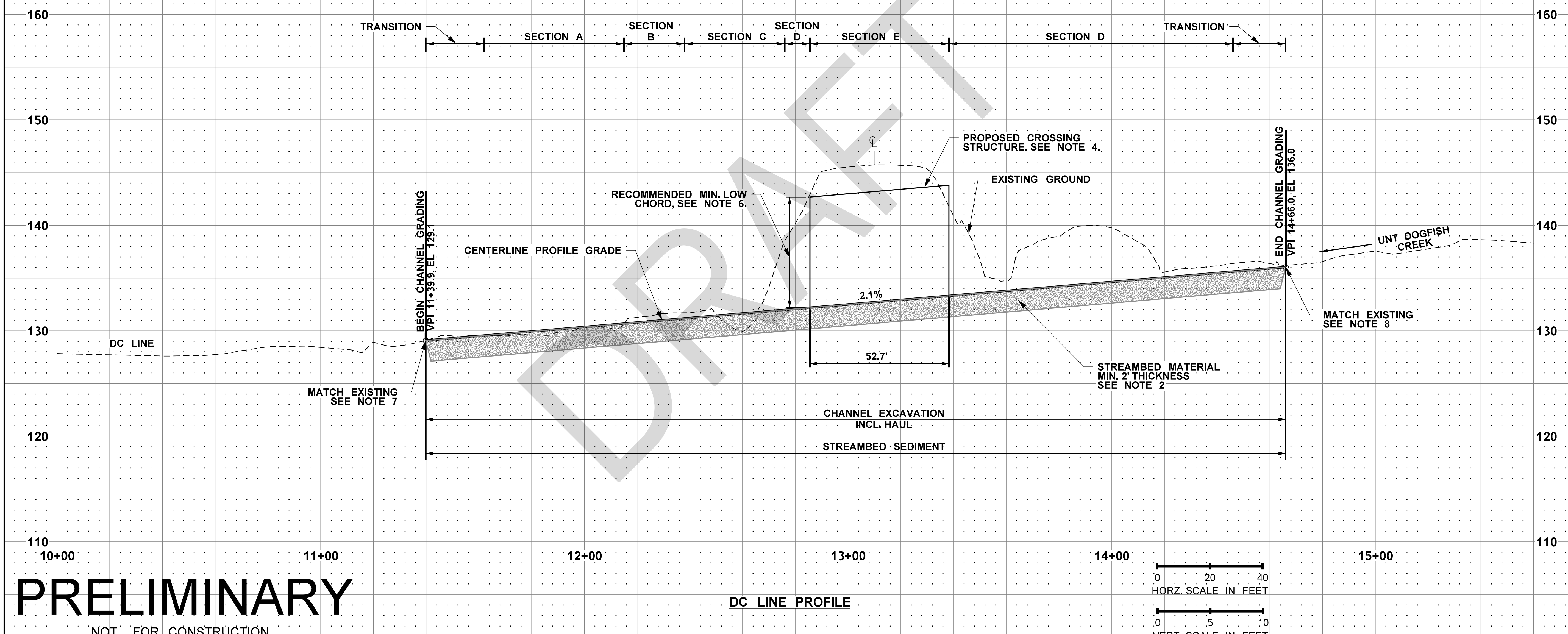
STREAM RESTORATION PLAN

PLAN REF NO HY02

SHEET 2 OF 4 SHEETS

NOTES:
1. EXISTING GROUND PROFILE SAMPLED DIGITAL TERRAIN MODEL DEVELOPED FROM WSDOT FIELD SURVEY (NAVD 88).
2. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH OF STREAMBED MATERIAL AND MINIMUM FOUNDATION DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
3. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.
4. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.
5. ALL STRUCTURAL ELEMENTS, INCLUDING ANY SOIL RELIED ON FOR LATERAL FOUNDATION SUPPORT, MUST BE OUTSIDE OF STRUCTURE FREE ZONE.
6. THE RECOMMENDED MINIMUM MAINTENANCE CLEARANCE IS 6 FEET ABOVE THE MAXIMUM SECTION GROUND ELEVATION WITHIN THE MINIMUM HYDRAULIC OPENING PLACING THE MINIMUM LOW CHORD 10.5 FEET ABOVE THE CHANNEL THALWEG.
7. FROM PR 11+39.9 TO PR 11+62.0, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.
8. FROM PR 14+46.0 TO PR 14+66, EVENLY TAPER SECTION E TO MATCH EXISTING CHANNEL.





DC LINE PROFILE

PRELIMINARY
NOT FOR CONSTRUCTION

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ENTERED BY	J. GERMAN
CHECKED BY	D. EGGERS
PROJ. ENGR.	
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 307
UNT DOGFISH CREEK
FISH BARRIER REMOVAL DESIGN
STREAM RESTORATION PROFILE

PLAN REF. NO. HY03
SHEET 3 OF 4 SHEETS

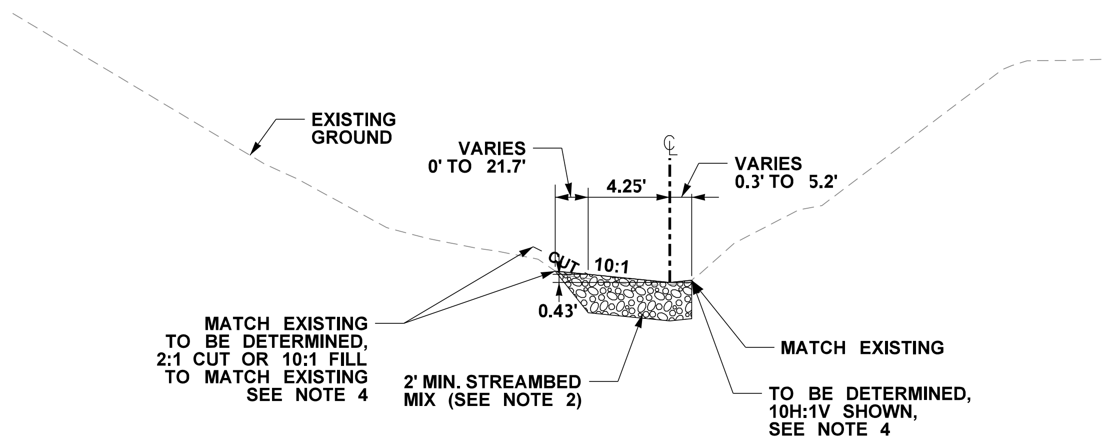
pw:\\HOOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order AC\700PROJTEC\2_PHD_Working\SR307_MP01-34_NEDogfishCk_991999_CAD_Sheets\991999_PR_HY_03

NOTES:

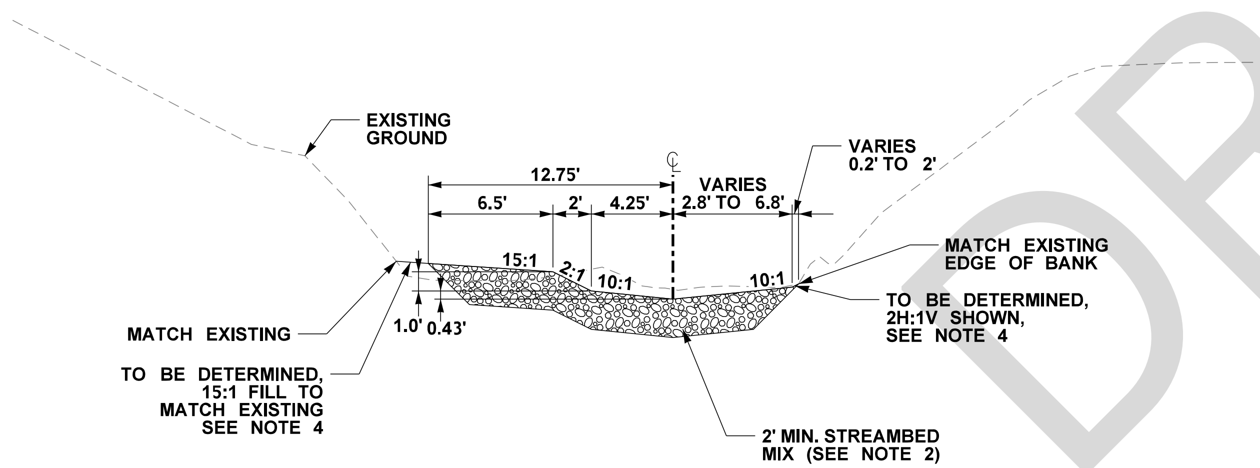
1. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.
2. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
3. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED. ALL STRUCTURAL ELEMENTS, INCLUDING ANY SOIL RELIED ON FOR LATERAL FOUNDATION SUPPORT, MUST BE OUTSIDE OF STRUCTURE FREE ZONE.
4. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.
5. FROM PR 11+39.9 TO PR 11+62.0, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.
6. FROM PR 14+46.0 TO PR 14+66, EVENLY TAPER SECTION E TO MATCH EXISTING CHANNEL.

DATUM

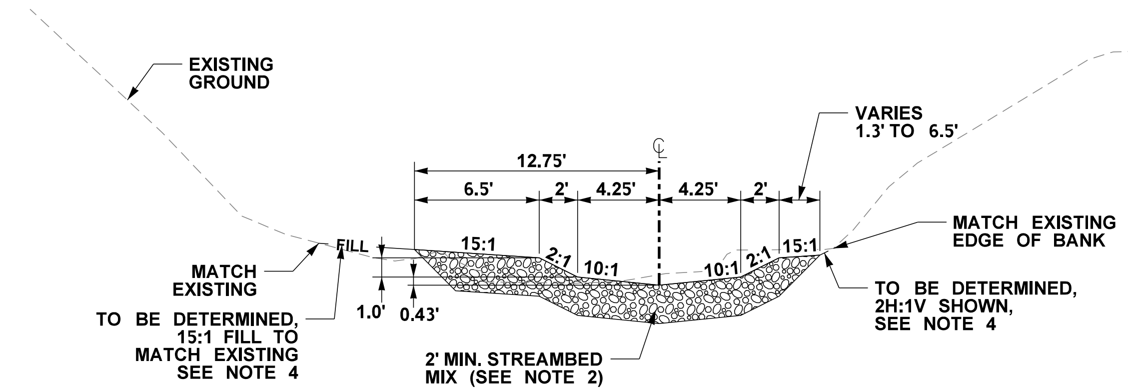
(NAVD) 88



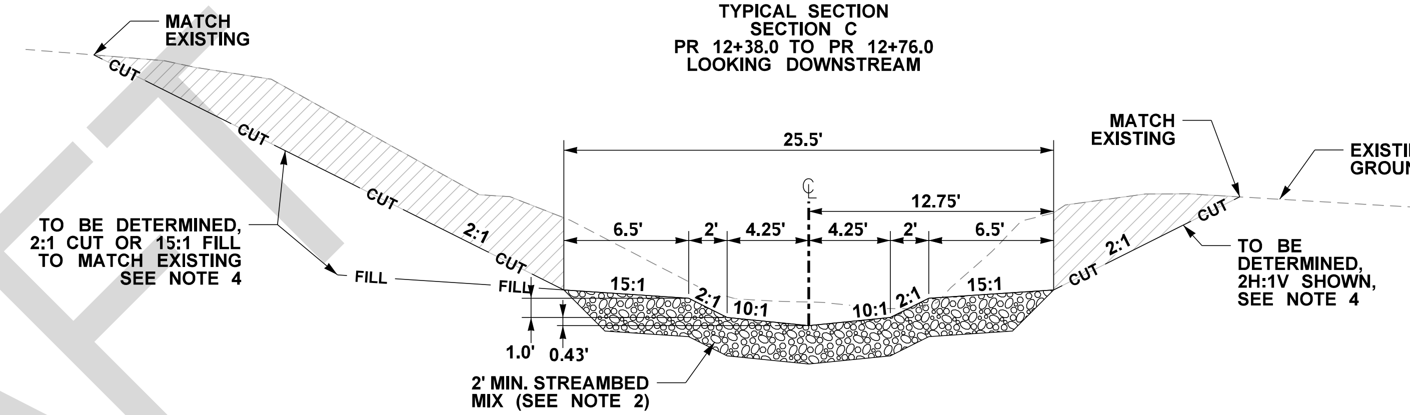
DOGFISH CREEK - LINE DC
TYPICAL SECTION
SECTION A
PR 11+62.0 TO PR 12+15.0
LOOKING DOWNSTREAM



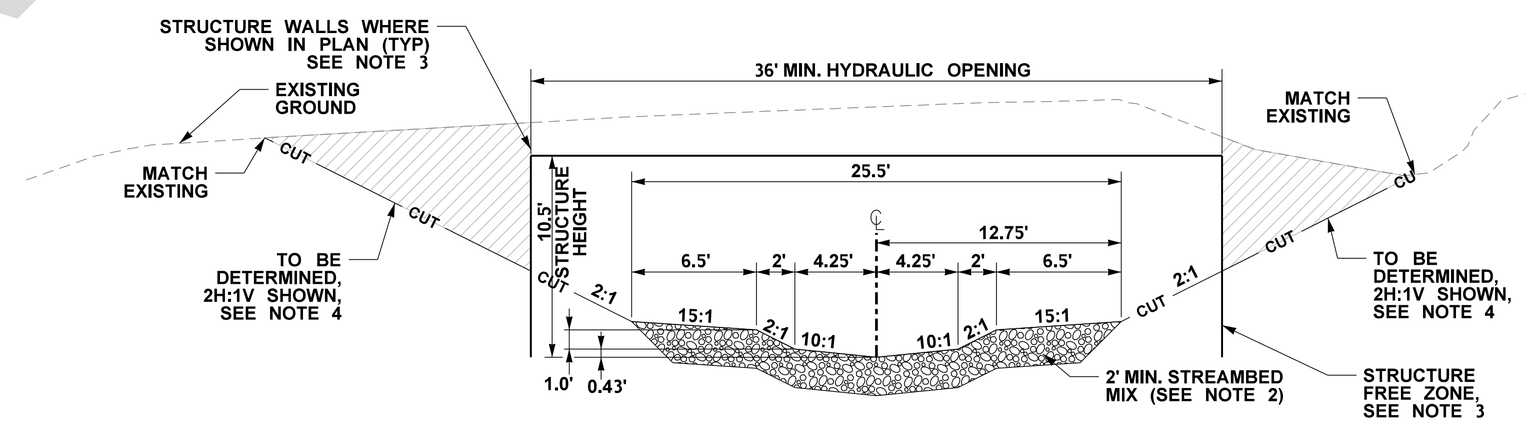
DOGFISH CREEK - LINE DC
TYPICAL SECTION
SECTION B
PR 12+15.0 TO PR 12+38.0
LOOKING DOWNSTREAM



DOGFISH CREEK - LINE DC
TYPICAL SECTION
SECTION C
PR 12+38.0 TO PR 12+76.0
LOOKING DOWNSTREAM



DOGFISH CREEK - LINE DC
TYPICAL SECTION
SECTION D
PR 12+76.0 TO PR 12+85.6
PR 13+38.3 TO PR 14+46.0
LOOKING DOWNSTREAM



DOGFISH CREEK - LINE DC
TYPICAL SECTION
SECTION E
PR 12+85.6 TO PR 13+38.3
LOOKING DOWNSTREAM

PRELIMINARY

NOT FOR CONSTRUCTION

0 5 10
HORZ. SCALE IN FEET

0 5 10
VERT. SCALE IN FEET

pw:\\HQOLYMAPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order AC\700PROJTEC\2_PHD_Working\SR307_MP01-34_NEDogfishCk_991999_CAD_Sheets\991999_PR_HY_04

FILE NAME	c:\pwworking\jgerman\wsdot\d0463002\991999_PR_HY_04.dgn
TIME	12:17:47 PM
DATE	11/11/2022
PLOTTED BY	jgerman
DESIGNED BY	A. MORTON
ENTERED BY	J. GERMAN
CHECKED BY	D. EGGERS
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX | DATE

P.E. STAMP BOX | DATE

Washington State Department of Transportation

SR 307
UNT DOGFISH CREEK
FISH BARRIER REMOVAL DESIGN

STREAM RESTORATION SECTIONS

PLAN REF NO HY04

SHEET 4 OF 4 SHEETS

Appendix E: Manning’s Calculations - If needed to support values chosen

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name:	Dogfish Creek	**Reach:**	Existing Upstream
Stream Slope, *S* (m/m):	0.01900	**Date:**	9/1/2022
		Practitioner:	Morgan McCarthy

Reach D_{50}, D_{84} (mm):	23.61	45.67	**Step D_{84} (mm)[a]:**	
Hydraulic Radius, *R* (m):				
Mean Flow Depth, *d* (m)[b]:				
Bedform Variation, σ_z (m)[c]:				
Median Thalweg Depth, h_m (m)[c]:				
Large Wood in Steps? (y/n)[c]:	n			

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 m/m (see sheet "S>0.03, Sigma z")

1 **Consult Tabular Guidance** → 2 **Consult Photographic** → 3 **Apply a Quantitative Prediction Method**

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	*f*	Use in Average? Enter "y"
Tabular Estimate:	0.047	----	y
Estimate from Photographic Guidance:	0.048	----	Y

Instructions: **(See technical summary report, TS-103, for more detailed instructions and references.)**

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: Dogfish Creek
Slope, *S* (m/m): 0.01900

Reach: Existing Upstream
Date: 9/1/2022
Practitioner: Morgan McCarthy

D_{50}, D_{84}, $D_{84,\,step}$ (m):	0.02	0.05	----
R (ft, m):	----	----	
d (ft^2, m^2):	----	----	
σ_z (ft, m):	----	----	
h_m (ft, m):	----	----	

Overall Average *n*:	0.050
***f*:**	----
Quantitative Average *n* (1):	----
***f* (1):**	----
Arcement and Schneider (1989) *n*:	0.055
***f*:**	----

3 Quantitative Prediction

Quasi-Quantitative:

	n_b (2)	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
Arcement and Schneider (1989) $n = (n_b + n_1 + n_2 + n_3 + n_4)m$	0.03	0	0	0.005	0.02	1	0.055	Y
	Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergenc	Estimate *n*	Estimate *f*	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub.(3)	Use in Average ? Enter
Yochum et al. (2012) [R^2 = 0.78; f: R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	----	----	----	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002)(4) [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84} (step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	----	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	----	----	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	----	----	----	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	
Hey (1979); a = 12.72	----	----	----	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	
Limerinos (1970) [R^2=0.77]	----	----	----	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be approprate to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or d and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is

This spreadsheet has been reviewed for accuracy. However, the ultimate responsibility for flow resistance estimates remains with the user.
U.S. Forest Service
National Stream and Aquatic Ecology Center

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: Dogfish Creek
Reach: Existing Downstream
Stream Slope, S (m/m): 0.02000
Date: 9/1/2022
Practitioner: Morgan McCarthy

Reach D_{50}, D_{84} (mm): 30.44 55.81
Step D_{84} (mm)[(a)]:
Hydraulic Radius, R (m):
Mean Flow Depth, d (m)[(b)]:
Bedform Variation, σ_z (m)[(c)]:
Median Thalweg Depth, h_m (m)[(c)]:
Large Wood in Steps? (y/n)[(c)]: n

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 m/m (see sheet "S>0.03, Sigma z")

1 **Consult Tabular Guidance** → 2 **Consult Photographic** → 3 **Apply a Quantitative Prediction Method**

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's n , Darcy-Weisbach f) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	f	Use in Average? Enter "y"
Tabular Estimate:	0.047	----	y
Estimate from Photographic Guidance:	0.048	----	Y

Instructions: **(See technical summary report, TS-103, for more detailed instructions and references.)**

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: Dogfish Creek
Slope, *S* (m/m): 0.02000

Reach: Existing Downstream
Date: 9/1/2022
Practitioner: Morgan McCarthy

D_{50}, D_{84}, $D_{84,\ step}$ (m):	0.03	0.06	----
R (ft, m):	----	----	
d (ft^2, m^2):	----	----	
σ_z (ft, m):	----	----	
h_m (ft, m):	----	----	

Overall Average *n*:	0.050
***f*:**	----
Quantitative Average *n*[1]:	----
***f*[1]:**	----
Arcement and Schneider (1989) *n*:	0.055
***f*:**	----

3 Quantitative Prediction

Quasi-Quantitative:

Arcement and Schneider (1989)
$$n = (n_b + n_1 + n_2 + n_3 + n_4)m$$

	n_b[2]	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
	0.03	0	0	0.005	0.02	1	0.055	Y
	Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergenc	Estimate *n*	Estimate *f*	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub.[3]	Use in Average ? Enter
Yochum et al. (2012) [R^2 = 0.78; *f* : R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	----	----	----	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002)[4] [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84} (step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	----	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	----	----	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	----	----	----	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	
Hey (1979); a = 12.72	----	----	----	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	
Limerinos (1970) [R^2=0.77]	----	----	----	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be appropraite to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or *d* and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is

This spreadsheet has been reviewed for accuracy. However, the ultimate responsibility for flow resistance estimates remains with the user.
U.S. Forest Service
National Stream and Aquatic Ecology Center

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name:	Dogfish Creek	**Reach:**	Proposed Conditions
Stream Slope, *S* (m/m):	0.01710	**Date:**	9/7/2022
		Practitioner:	Morgan McCarthy

Reach D_{50}, D_{84} (mm):	30.44	55.81	**Step D_{84} (mm)[(a)]:**	
Hydraulic Radius, *R* (m):				
Mean Flow Depth, *d* (m)[(b)]:				
Bedform Variation, σ_z (m)[(c)]:				
Median Thalweg Depth, h_m (m)[(c)]:				
Large Wood in Steps? (y/n)[(c)]:	n			

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 m/m (see sheet "S>0.03, Sigma z")

1 **Consult Tabular Guidance** → 2 **Consult Photographic** → 3 **Apply a Quantitative Prediction Method**

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	*f*	Use in Average? Enter "y"
Tabular Estimate:	0.045	----	y
Estimate from Photographic Guidance:	0.057	----	Y

Instructions: (See technical summary report, TS-103, for more detailed instructions and references.)

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
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(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: Dogfish Creek
Slope, *S* (m/m): 0.01710

Reach: Proposed Conditions
Date: 9/7/2022
Practitioner: Morgan McCarthy

D_{50}, D_{84}, $D_{84,\,step}$ (m):	0.03	0.06	----
R (ft, m):	----	----	
d (ft^2, m^2):	----	----	
σ_z (ft, m):	----	----	
h_m (ft, m):	----	----	

Overall Average *n*:	0.100
***f*:**	----
Quantitative Average *n* (1):	----
***f* (1):**	----
Arcement and Schneider (1989) *n*:	0.197
***f*:**	----

3 Quantitative Prediction

Quasi-Quantitative:

	n_b (2)	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
Arcement and Schneider (1989) $n = (n_b + n_1 + n_2 + n_3 + n_4)m$	0.1	0	0	0.047	0.05	1	0.197	Y
	Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergenc	Estimate *n*	Estimate *f*	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub. (3)	Use in Average ? Enter
Yochum et al. (2012) [R^2 = 0.78; f: R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	----	----	----	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002) (4) [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84} (step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	----	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	----	----	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	----	----	----	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	
Hey (1979); a = 12.72	----	----	----	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	
Limerinos (1970) [R^2=0.77]	----	----	----	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be appropraite to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or *d* and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is

This spreadsheet has been reviewed for accuracy. However, the ultimate responsibility for flow resistance estimates remains with the user.
U.S. Forest Service
National Stream and Aquatic Ecology Center

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name:	Dogfish Creek	**Reach:**	Proposed Conditions
Stream Slope, *S* (m/m):	0.01710	**Date:**	9/7/2022
		Practitioner:	Morgan McCarthy

Reach D_{50}, D_{84} (mm):	700	900	**Step D_{84} (mm)[(a)]:**	
Hydraulic Radius, *R* (m):				
Mean Flow Depth, *d* (m)[(b)]:				
Bedform Variation, σ_z (m)[(c)]:				
Median Thalweg Depth, h_m (m)[(c)]:				
Large Wood in Steps? (y/n)[(c)]:	n			

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 m/m (see sheet "S>0.03, Sigma z")

1 **Consult Tabular Guidance** → 2 **Consult Photographic** → 3 **Apply a Quantitative Prediction Method**

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	*f*	Use in Average? Enter "y"
Tabular Estimate:	0.045	----	n
Estimate from Photographic Guidance:	0.057	----	n

Instructions: (See technical summary report, TS-103, for more detailed instructions and references.)

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

NATIONAL STREAM & AQUATIC ECOLOGY CENTER

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: Dogfish Creek
Slope, *S* (m/m): 0.01710

Reach: Proposed Conditions
Date: 9/7/2022
Practitioner: Morgan McCarthy

D_{50}, D_{84}, $D_{84,\,step}$ (m):	0.7	0.9	----
R (ft, m):	----	----	
d (ft^2, m^2):	----	----	
σ_z (ft, m):	----	----	
h_m (ft, m):	----	----	

Overall Average *n*:	0.109
***f*:**	----
Quantitative Average *n* (1):	----
***f* (1):**	----
Arcement and Schneider (1989) *n*:	0.109
***f*:**	----

3 Quantitative Prediction

Quasi-Quantitative:

	n_b (2)	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
Arcement and Schneider (1989) $n = (n_b + n_1 + n_2 + n_3 + n_4)m$	0.03	0	0.004	0.045	0.03	1	0.109	Y
	Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergenc	Estimate *n*	Estimate *f*	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub. (3)	Use in Average ? Enter
Yochum et al. (2012) [R^2 = 0.78; *f*: R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	----	----	----	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002) (4) [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84} (step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	----	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	----	----	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	----	----	----	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	
Hey (1979); a = 12.72	----	----	----	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	
Limerinos (1970) [R^2=0.77]	----	----	----	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be appropraite to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or *d* and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name:	Dogfish Creek	**Reach:**	Natural Conditions
Stream Slope, *S* (m/m):	0.01800	**Date:**	9/7/2022
		Practitioner:	Morgan McCarthy
Reach D_{50}, D_{84} (mm):	150 164	**Step D_{84} (mm)[(a)]:**	
Hydraulic Radius, *R* (m):			
Mean Flow Depth, *d* (m)[(b)]:			
Bedform Variation, σ_z (m)[(c)]:			
Median Thalweg Depth, h_m (m)[(c)]:			
Large Wood in Steps? (y/n)[(c)]:	n		

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 m/m (see sheet "S>0.03, Sigma z")

1 **Consult Tabular Guidance** → 2 **Consult Photographic** → 3 **Apply a Quantitative Prediction Method**

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	*f*	Use in Average? Enter "y"
Tabular Estimate:	0.033	----	y
Estimate from Photographic Guidance:	0.057	----	Y

Instructions: (See technical summary report, TS-103, for more detailed instructions and references.)

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: Dogfish Creek
Slope, *S* (m/m): 0.01800

Reach: Natural Conditions
Date: 9/7/2022
Practitioner: Morgan McCarthy

D_{50}, D_{84}, $D_{84,\ step}$ (m):	0.15	0.16	----
R (ft, m):	----	----	
d (ft^2, m^2):	----	----	
σ_z (ft, m):	----	----	
h_m (ft, m):	----	----	

Overall Average *n* :	0.050
***f* :**	----
Quantitative Average *n* (1):	----
***f* (1):**	----
Arcement and Schneider (1989) *n* :	0.060
***f* :**	----

3 Quantitative Prediction

Quasi-Quantitative:

	n_b (2)	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
Arcement and Schneider (1989) $n = (n_b + n_1 + n_2 + n_3 + n_4)m$	0.035	0	0	0.005	0.02	1	0.060	Y
	Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergenc	Estimate *n*	Estimate *f*	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub.(3)	Use in Average ? Enter
Yochum et al. (2012) [R^2 = 0.78; f: R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	----	----	----	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002)(4) [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84} (step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	----	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	----	----	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	----	----	----	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	
Hey (1979); a = 12.72	----	----	----	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	
Limerinos (1970) [R^2=0.77]	----	----	----	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be approprate to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or *d* and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is

This spreadsheet has been reviewed for accuracy. However, the ultimate responsibility for flow resistance estimates remains with the user.
U.S. Forest Service
National Stream and Aquatic Ecology Center

Appendix F: Large Woody Material Calculations

LWM density and volume calculations to be included in PHD and FHD.

LWM stability calculations to be included in FHD.

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	*SR307 MP1.34*		Key piece volume	**1.310**	*yd3*
Stream name	*Dog Fish Creek*		Key piece/ft	**0.0335**	*per ft stream*
length of regrade[a]	*326.13*	*ft*	Total wood vol./ft	**0.3948**	*yd3/ft stream*
Bankfull width	*12.4*	*ft*	Total LWM[c] pieces/ft stream	**0.1159**	*per ft stream*
Habitat zone[b]	*Western WA*				

Taper coeff.	-0.01554
LF_{rw}	1.5
H_{dbh}	4.5

yes
no

Log type	*Diameter at midpoint (ft)*	*Length(ft)[d]*	*Volume (yd^3/log)[d]*	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*
A	2.50	*30*	5.45	**yes**	yes	20	109.08
B	2.50	*30*	5.45	**no**	yes	20	109.08
C			0.00				0.00
D			0.00				0.00
E			0.00				0.00
F			0.00				0.00
G			0.00				0.00
H			0.00				0.00
I			0.00				0.00
J			0.00				0.00
K			0.00				0.00
L			0.00				0.00
M			0.00				0.00
N			0.00				0.00
O			0.00				0.00
P			0.00				0.00

DBH based on mid point diameter (ft)	$D_{root\ collar\ (ft)}$	L/2-Lrw (ft)
2.60	2.67	11.25
2.73	2.67	11.25
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0
	0.00	0

Log volume for stability calcs (yd^3, per log)	
rootwad	bole
2.36	4.77
0.00	5.45
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	40	40	218.2
Targets	**11**	**38**	**128.8**
	surplus	surplus	surplus

[a] includes length through crossing, regardless of structure type

[b] choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information

Western Washington lowla (generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine (generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa pine (mainly east slope Cascades below 3,700 ft. elevation)

[c]LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).

[d]includes rootwad if present

Key piece volume

BFW class (ft)	volume (yd3)
0-16	1.31
17-33	3.28
34-49	7.86
50-66	11.79
67-98	12.77
99-164	13.76
165-328	14.08

adapted from Fox and Bolton (2007), Table 5

Key Piece density lookup table

Habitat zone	BFW class (feet)	75th percentile (yd3/ft stream)
Western WA	0-33	0.0335
	34-328	0.0122
Alpine	0-49	0.0122
	50-164	0.0030
Douglas Fir/Pond. Pine (much of eastern WA)	0-98	0.0061

adapted from Fox and Bolton (2007), Table 4

Total Wood Volume lookup table

Habitat zone	BFW class (feet)	75th percentile (yd3/ft stream)
Western WA	0-98	0.3948
	99-328	1.2641
Alpine	0-10	0.0399
	11-164	0.1196
Douglas Fir/Pond. Pine	0-98	0.0598

adapted from Fox and Bolton (2007), Table 4

Number of LWM pieces lookup table

Habitat zone	BFW class (feet)	75th percentile (per/ft stream)
Western WA	0-20	0.1159
	21-98	0.1921
	99-328	0.6341
Alpine	0-10	0.0854
	11-98	0.1707
	99-164	0.1921
Douglas Fir/Pond.	0-20	0.0884
	21-98	0.1067

adapted from Fox and Bolton (2007), Table 4

Appendix G: Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name:	WSDOT Remove Fish Barrier
Stream Name:	Crossing 991999 - Dogfish Creek
Drainage Area:	679 ac

Projected mean percent change in bankfull flow:

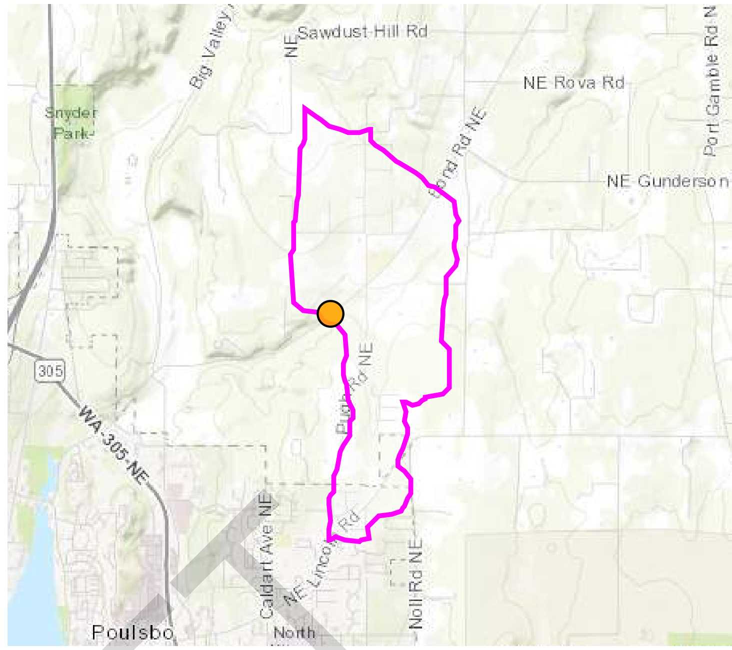
2040s:	13.8%
2080s:	16.8%

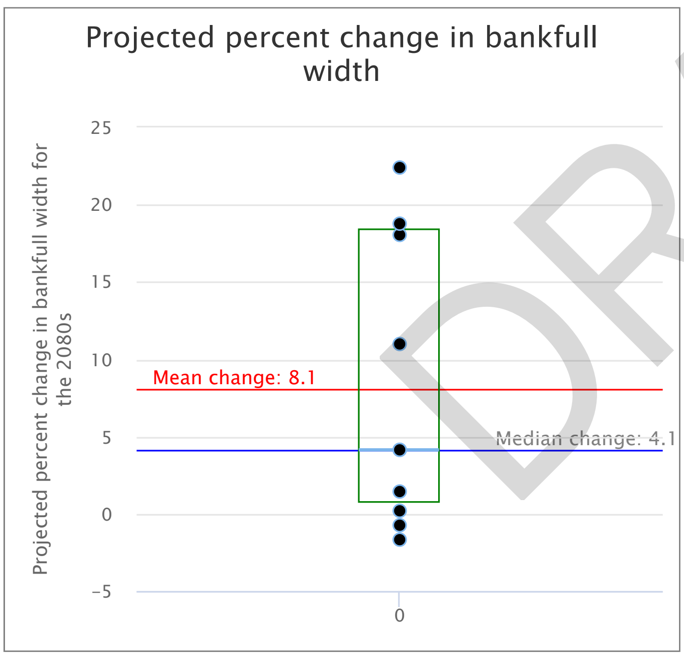
Projected mean percent change in bankfull width:

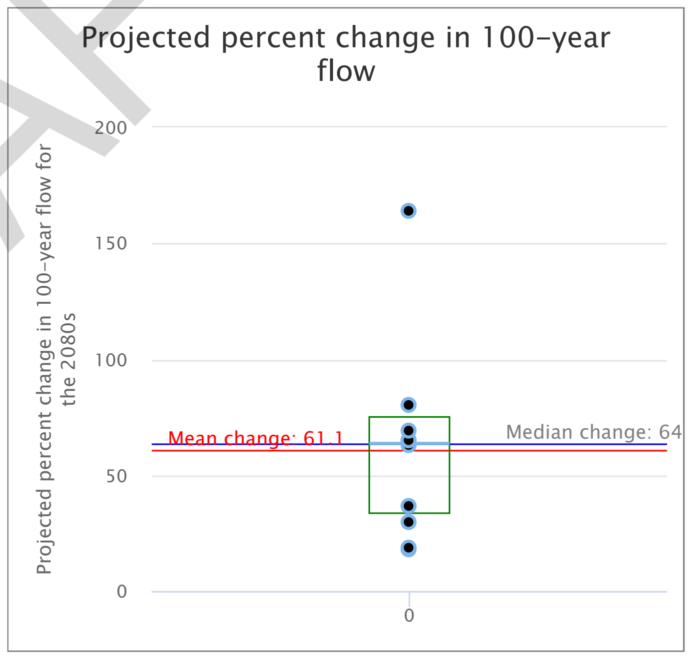
2040s:	6.7%
2080s:	8.1%

Projected mean percent change in 100-year flood:

2040s:	42.5%
2080s:	61.1%

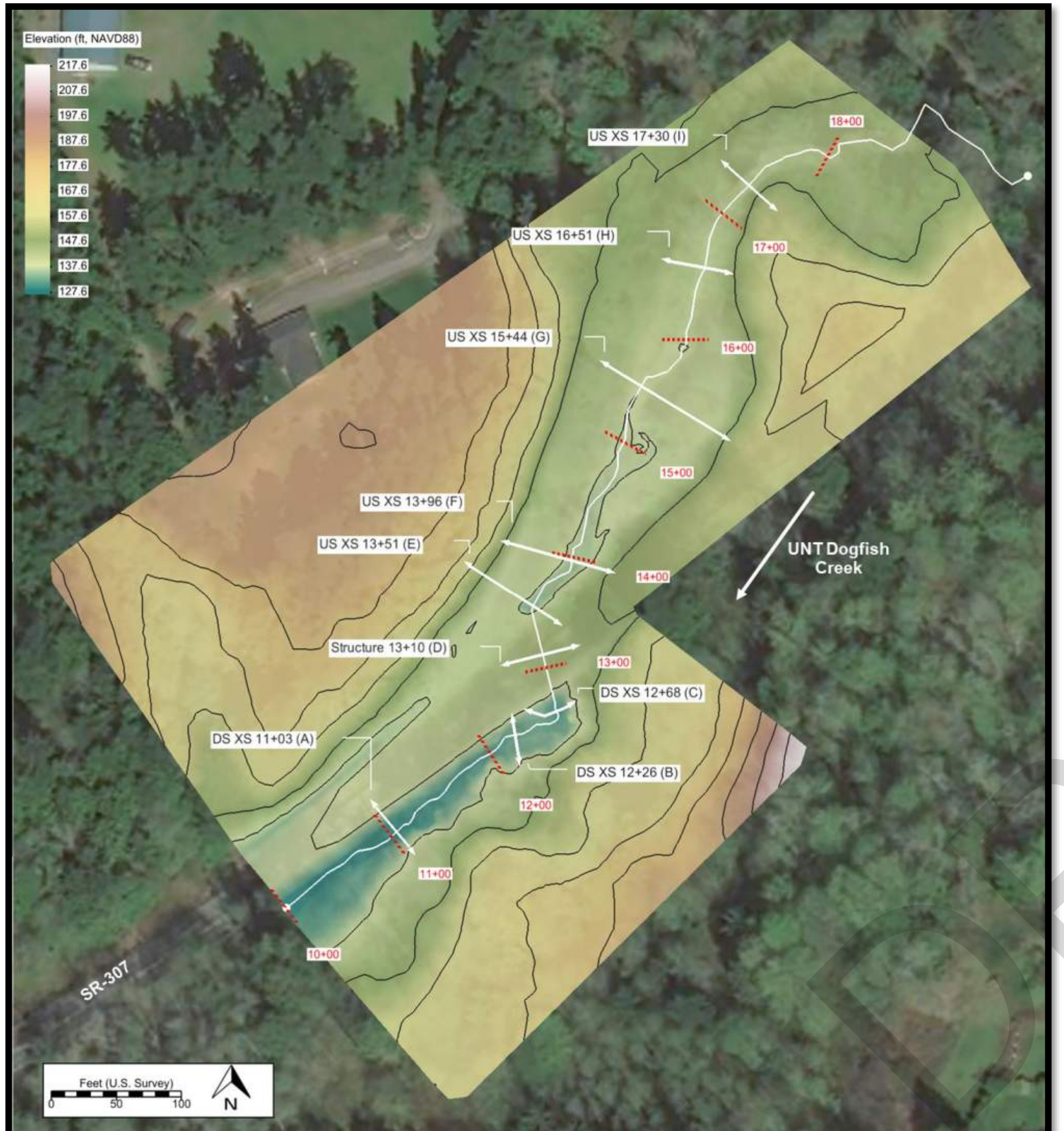




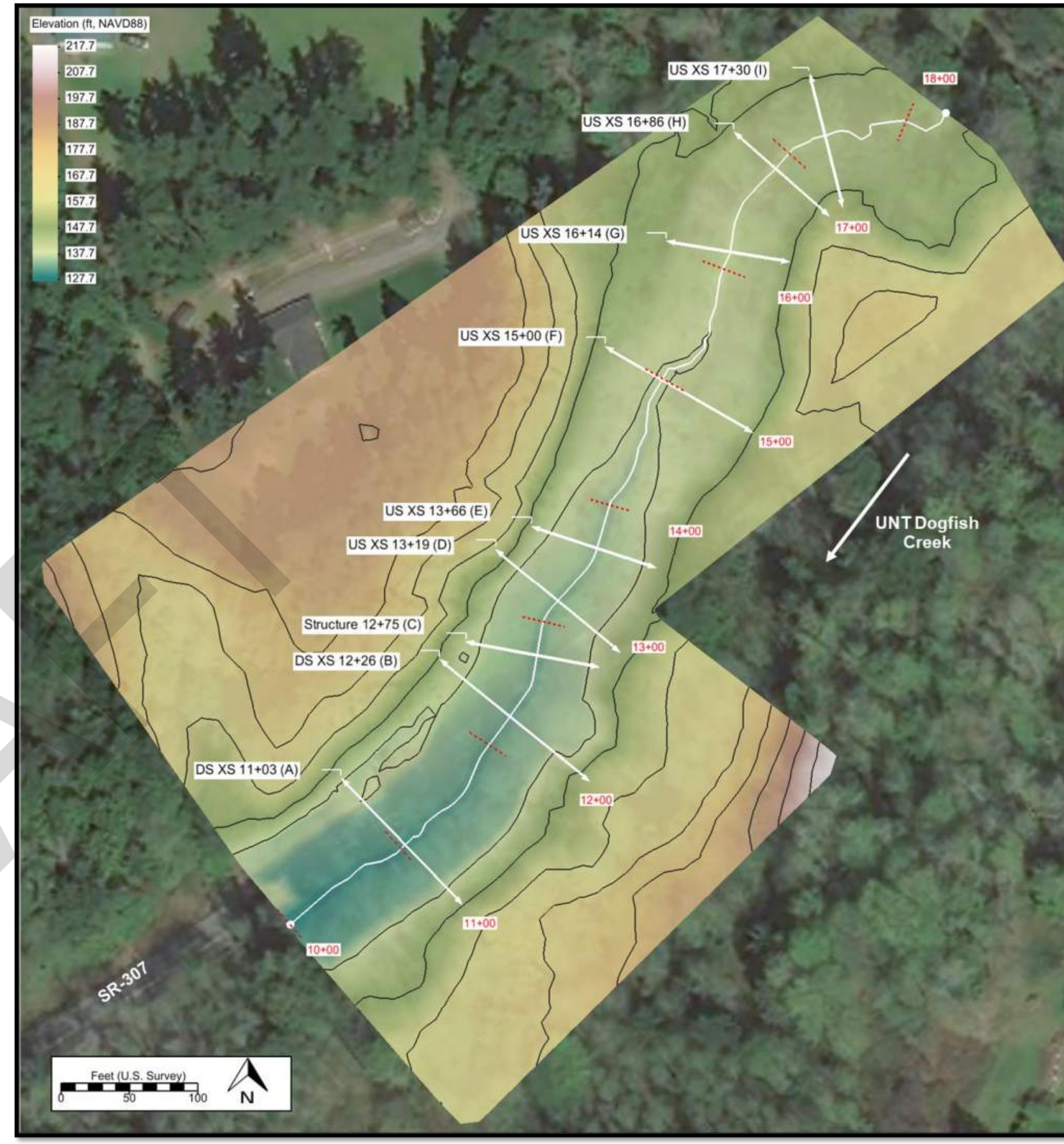


Black dots are projections from 10 separate models

Appendix H: SRH-2D Model Results



Existing Conditions



Natural Conditions

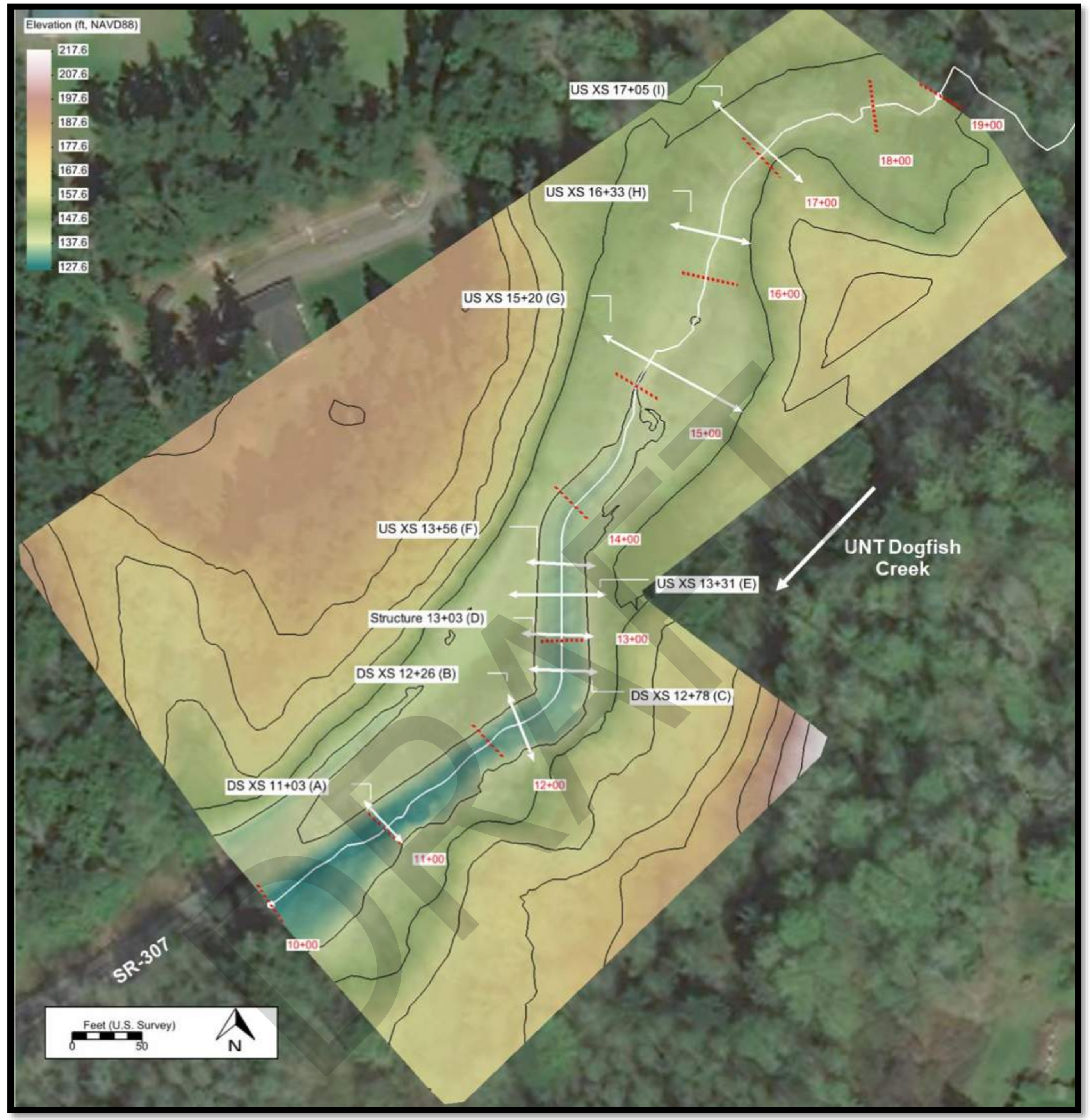
Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Profile and Cross Section Locations Relative to Crossing	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-1

00180-406-01 Date Exported: 09-21-22



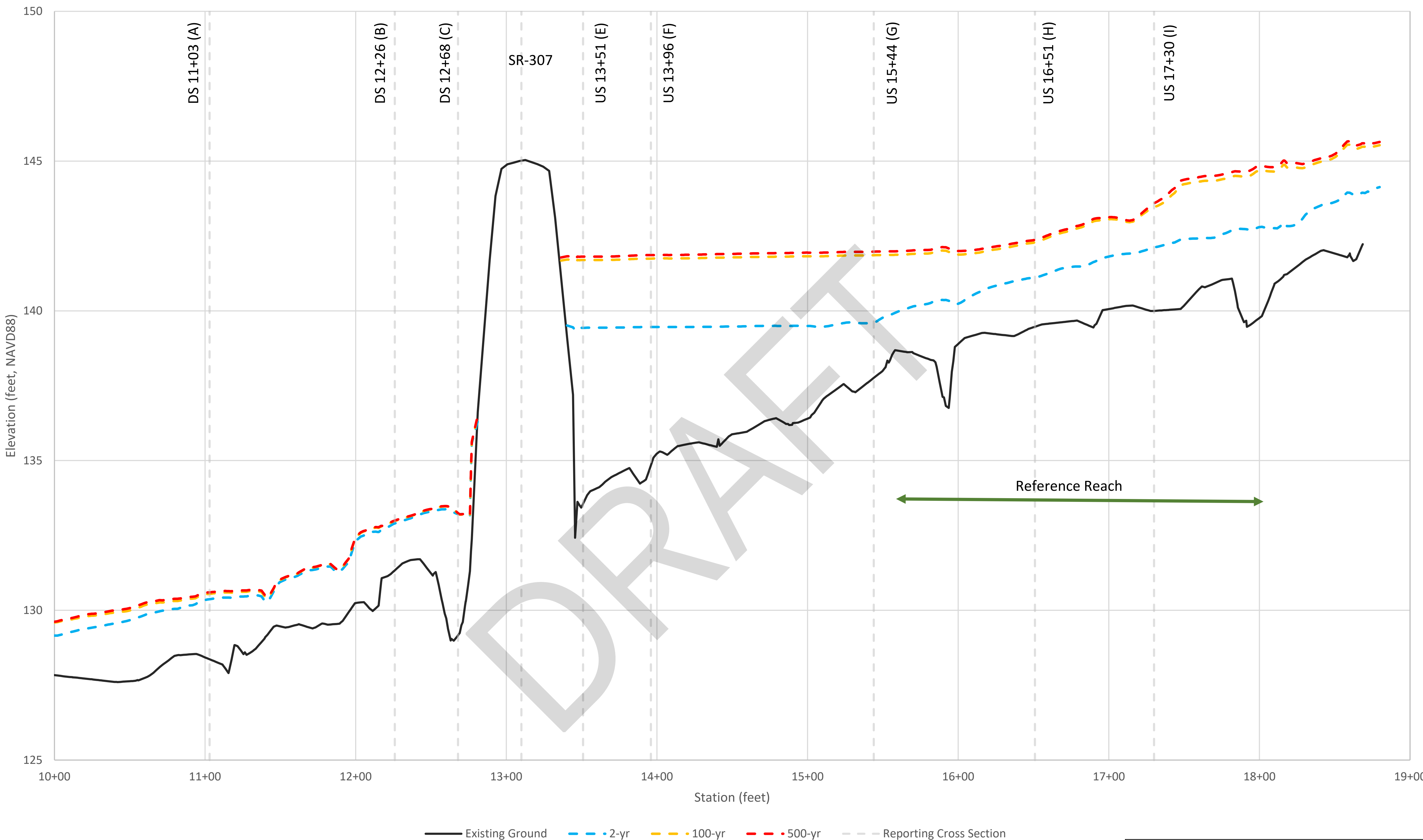
Proposed Conditions

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Profile and Cross Section Locations Relative to Crossing	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-2

00180-406-01 Date Exported: 09-21-22



Existing Conditions

Notes:
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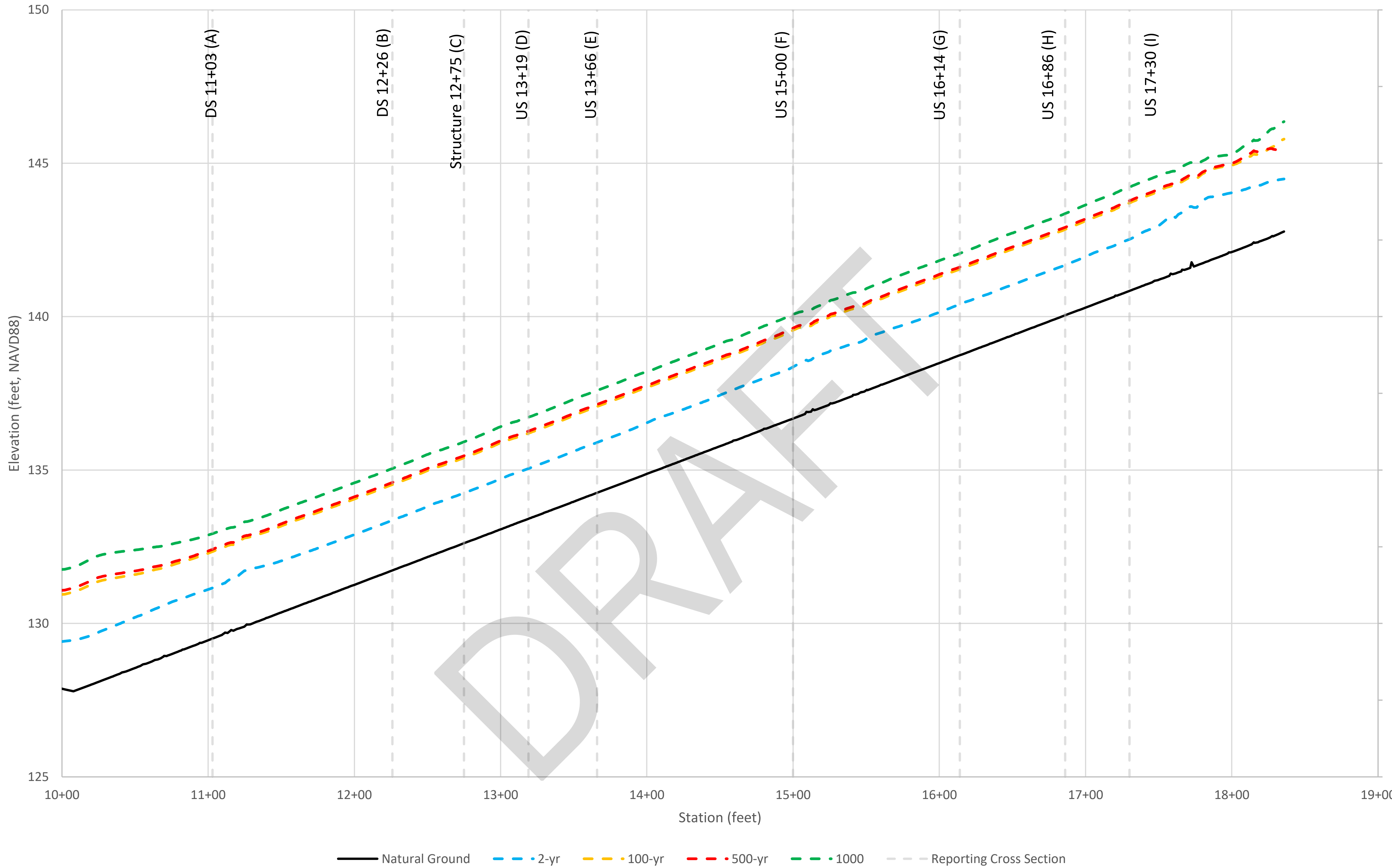
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Existing Conditions **Water Surface Elevation Profiles Through Crossing**	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	**Figure H-3**

00180-406-01 Date Exported: 09-21-22



Natural Conditions

Notes:
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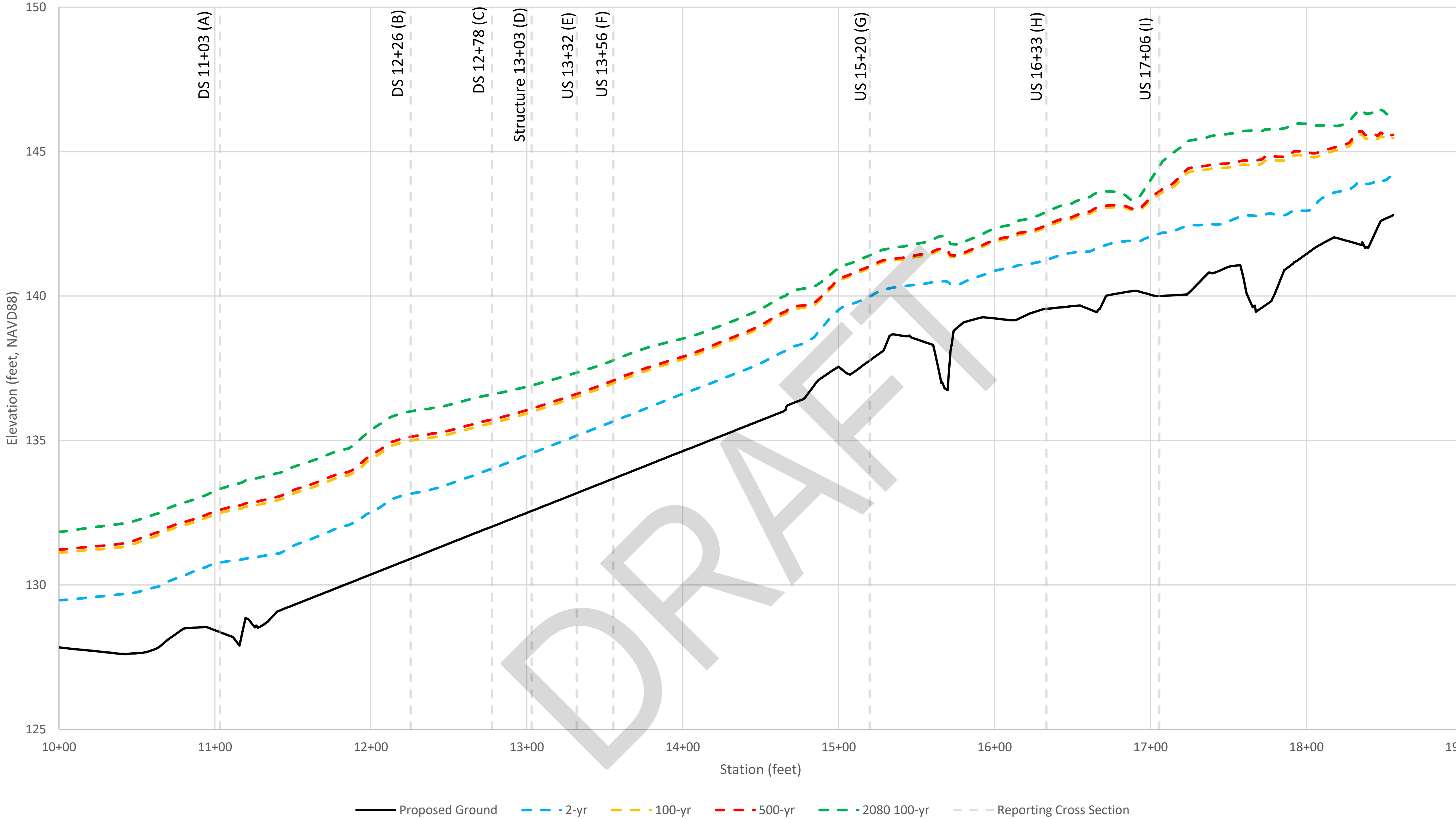
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Natural Conditions Water Surface Elevation Profiles Through Crossing	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-4

00180-406-01 Date Exported: 09-21-22



Proposed Conditions

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

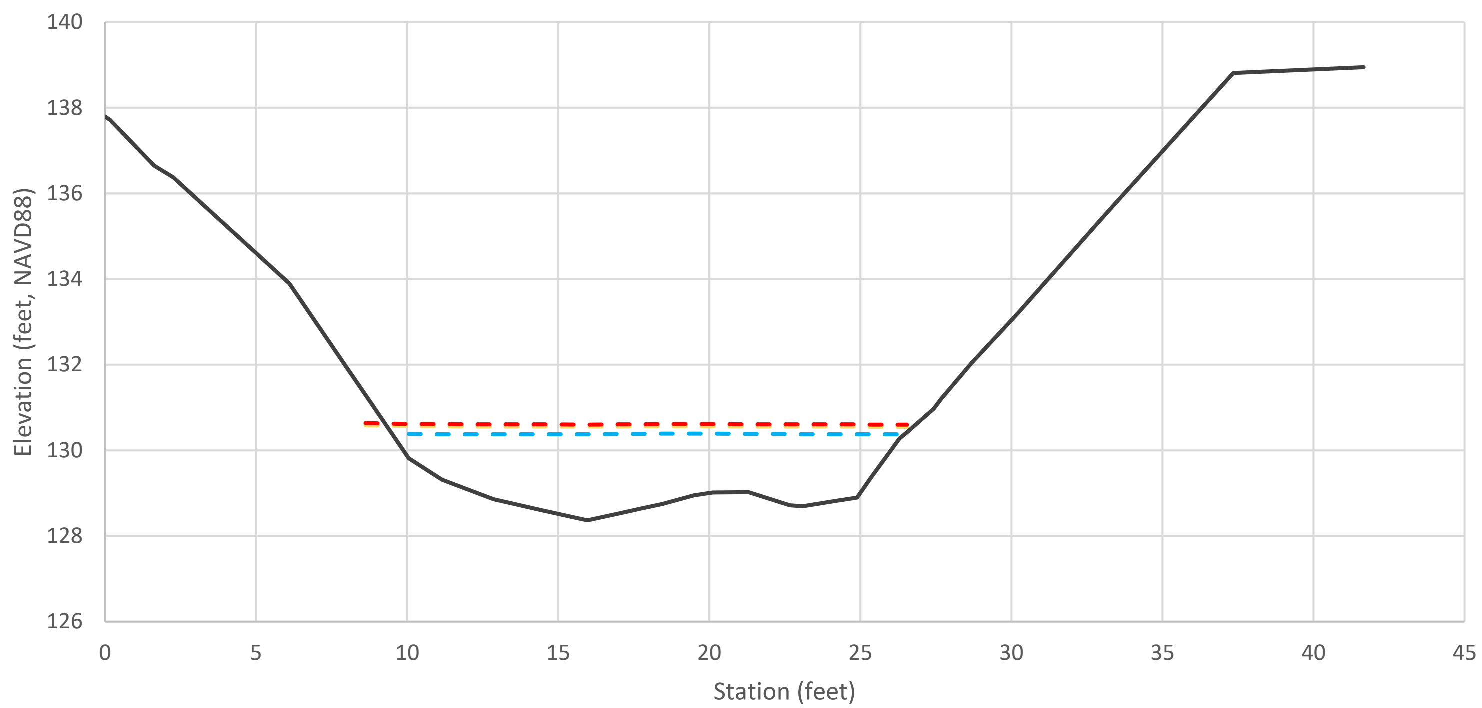
Proposed Conditions
Water Surface Elevation Profiles Through Crossing

Dogfish Creek
Kitsap County

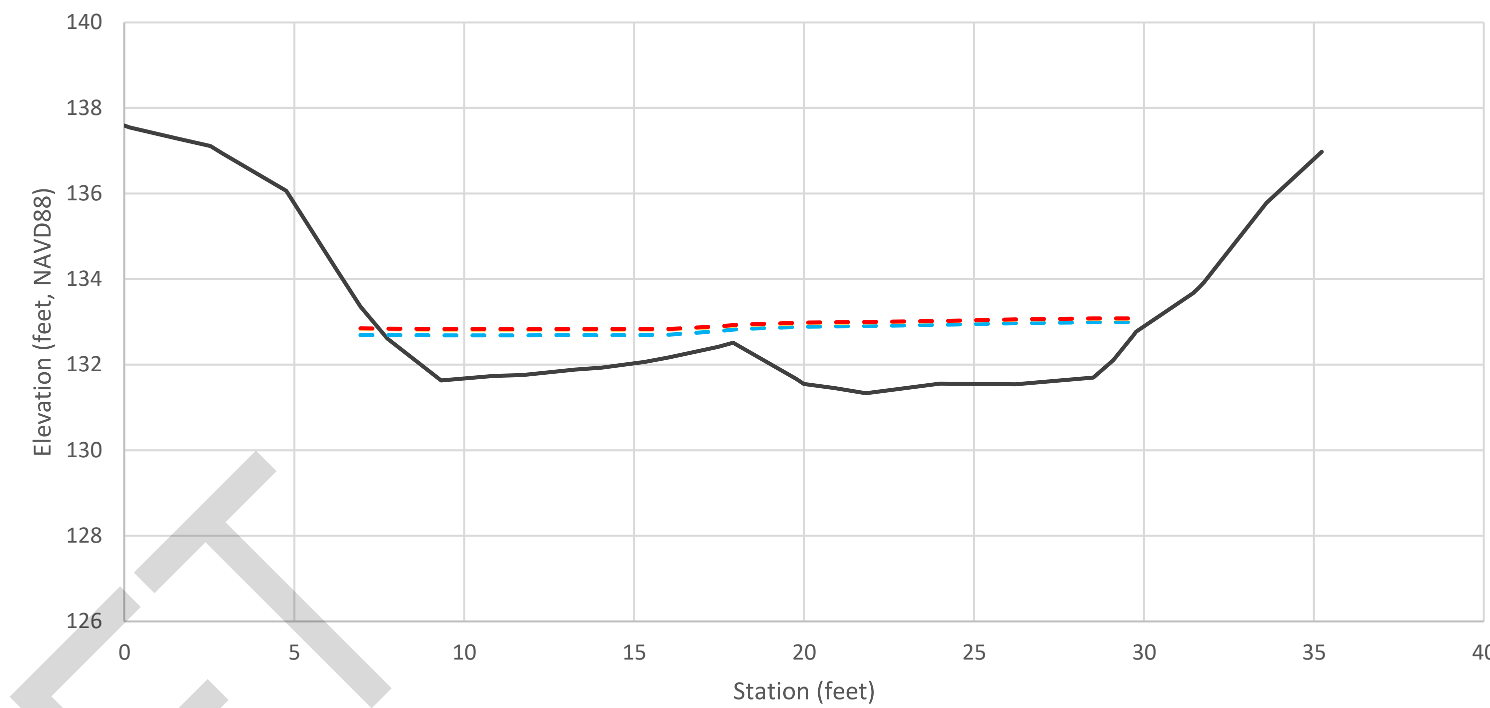
WSDOT GeoEngineers

Figure H-5

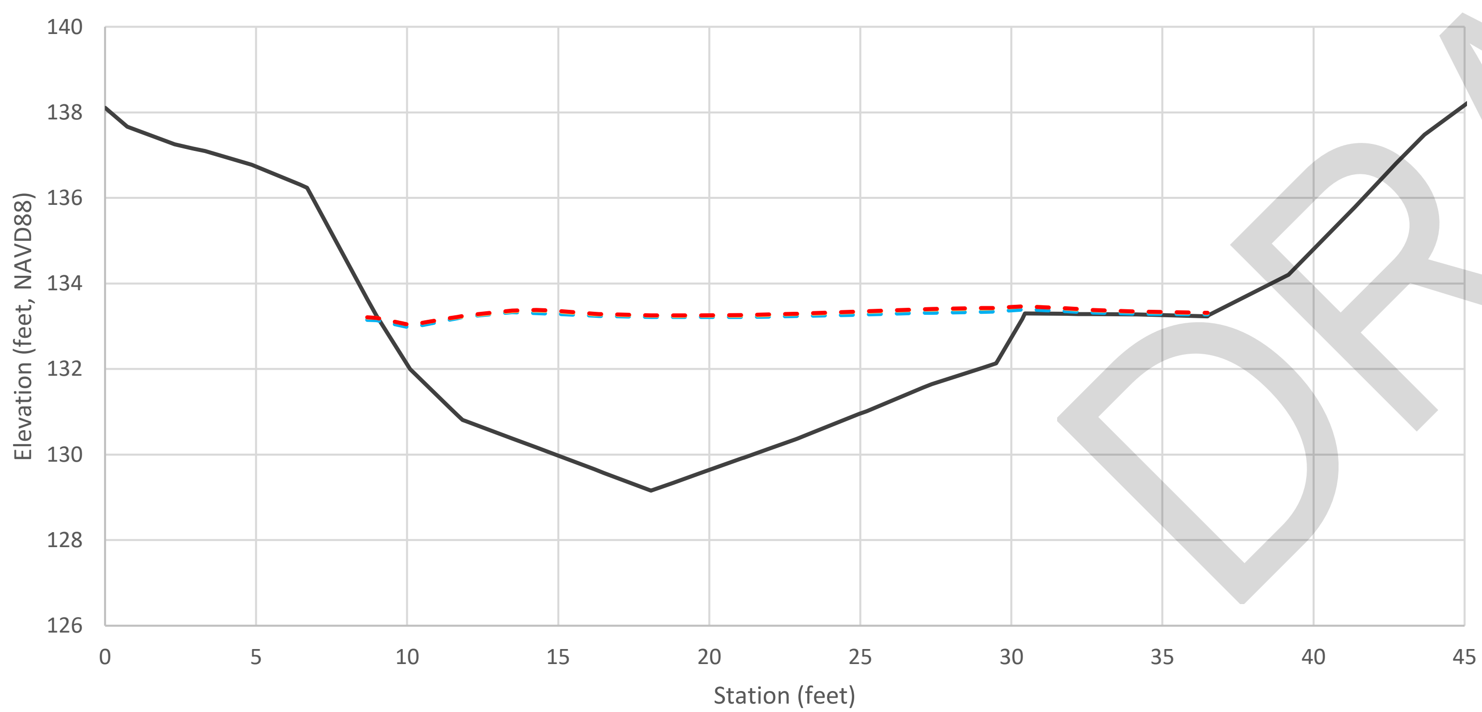
00180-406-01 Date Exported: 09-21-22



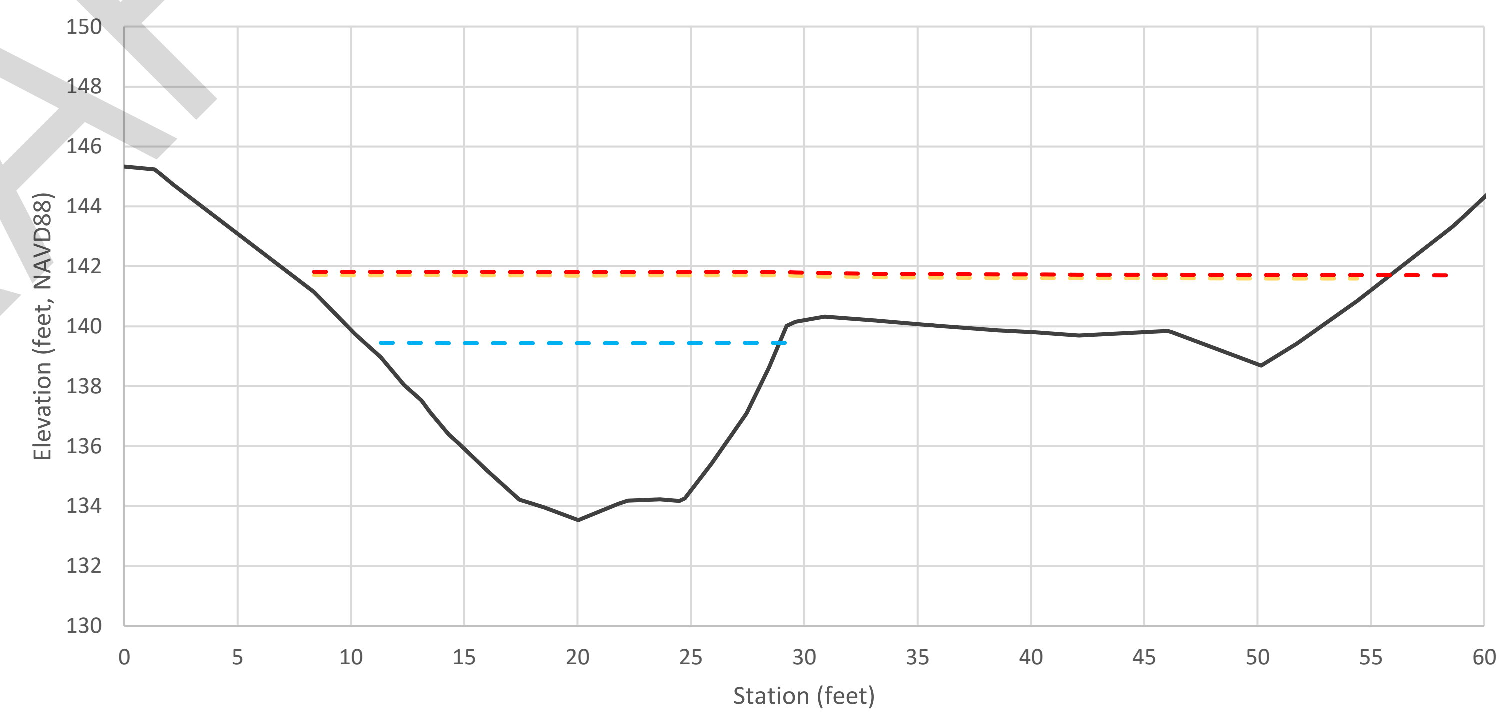
Cross Section A – Downstream STA 11+03



Cross Section B – Downstream 12+26



Cross Section C – Downstream STA 12+68



Cross Section E – Upstream STA 13+51

Ground — 2-yr — 100-yr — 500-yr

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
3. All cross sections are looking downstream.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

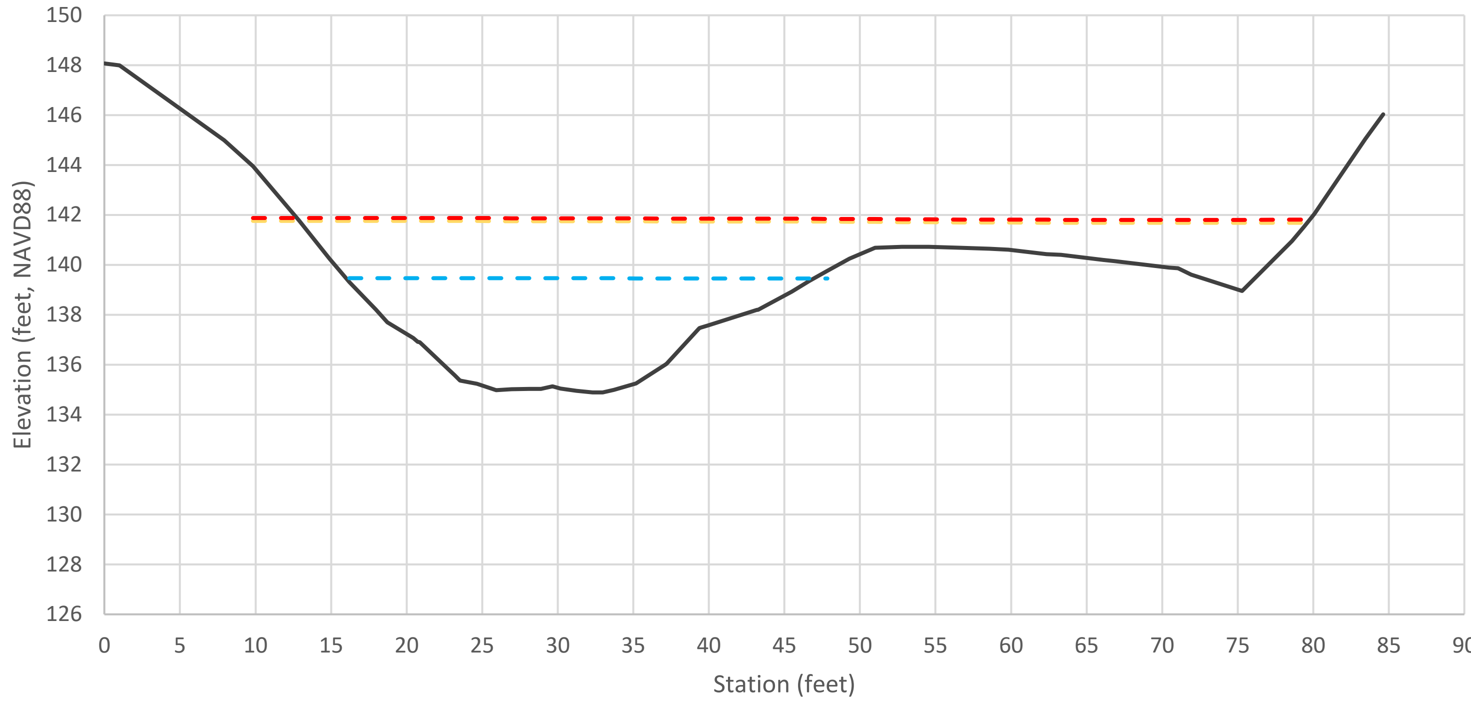
Existing Conditions
Water Surface Elevation at Cross Sections

UNT Dogfish Creek
Kitsap County

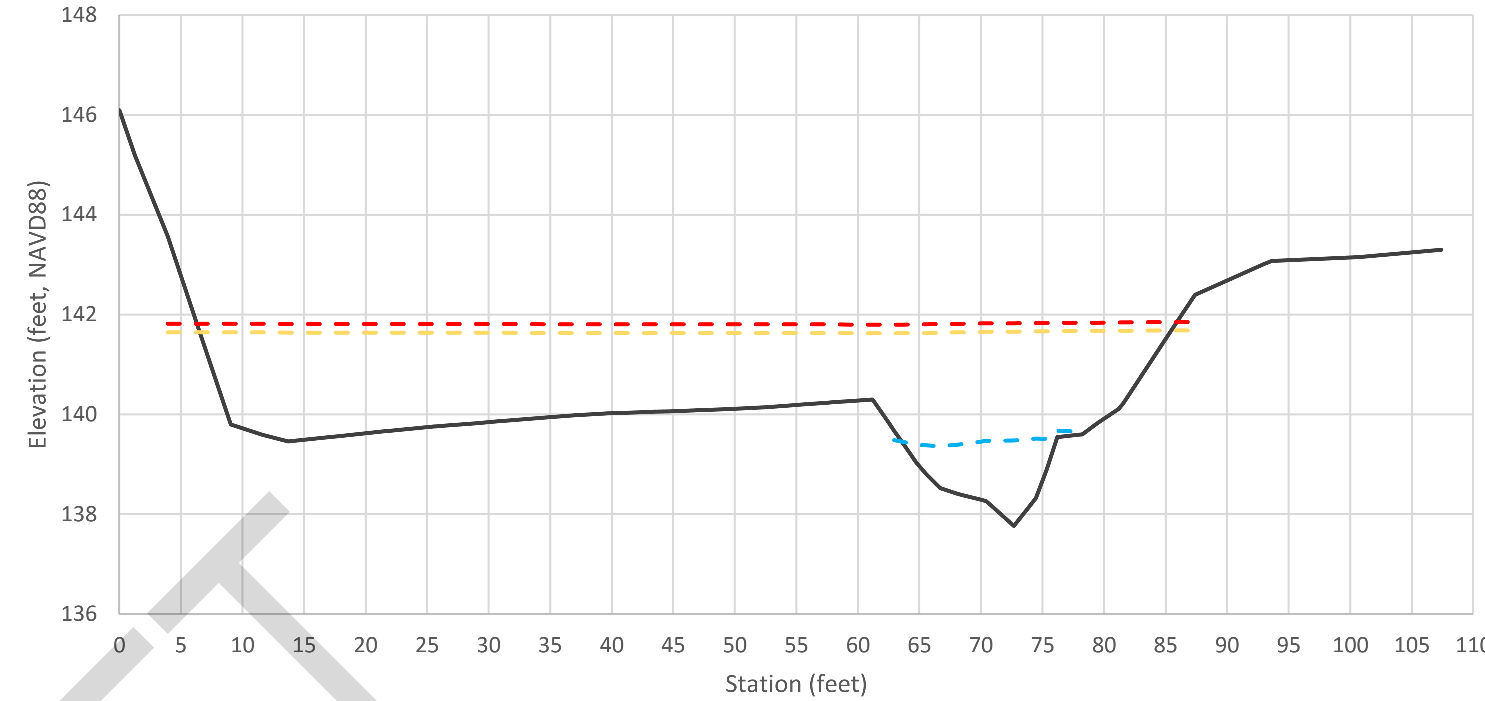
WSDOT GeoEngineers

Figure H-6

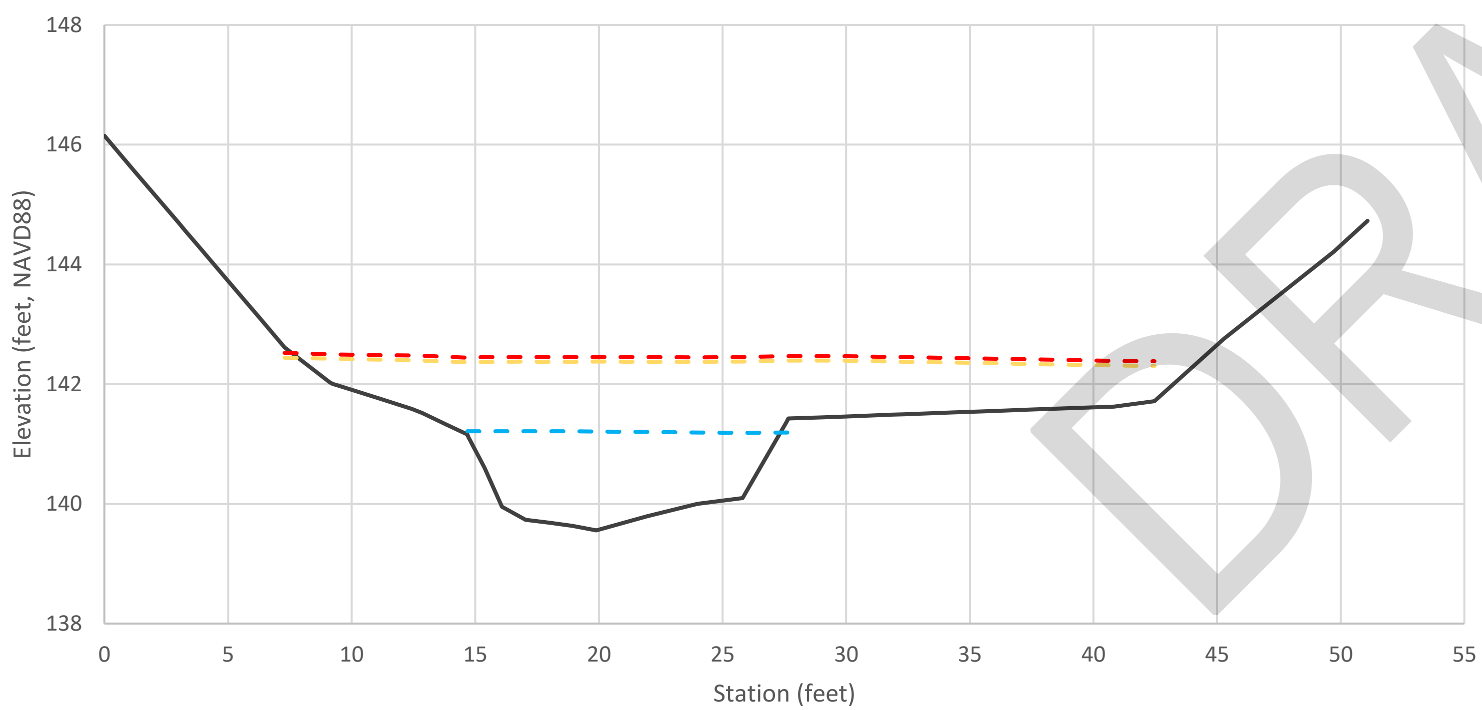
00180-406-01 Date Exported: 09-21-22



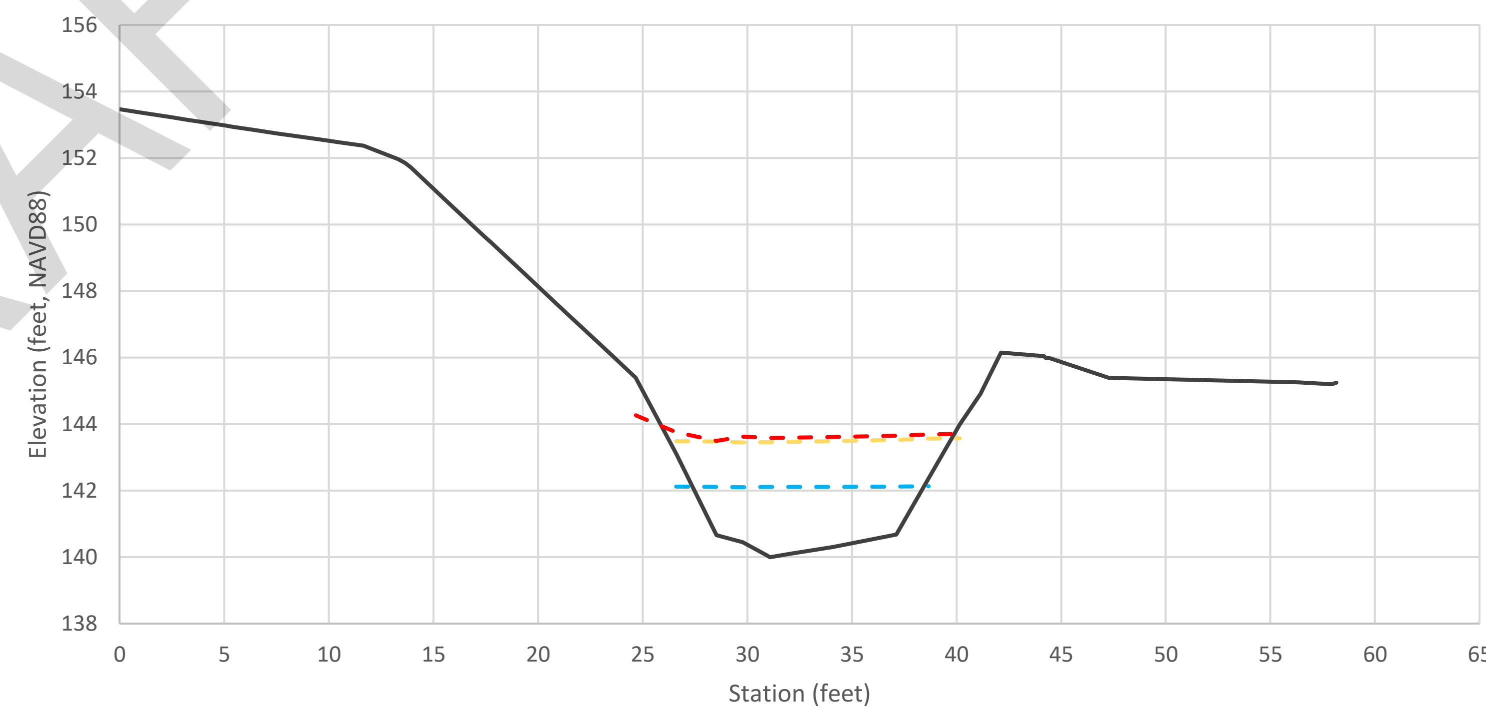
Cross Section F – Upstream 13+96



Cross Section G – Upstream 15+44



Cross Section H – Upstream 16+51



Cross Section I – Upstream 17+30

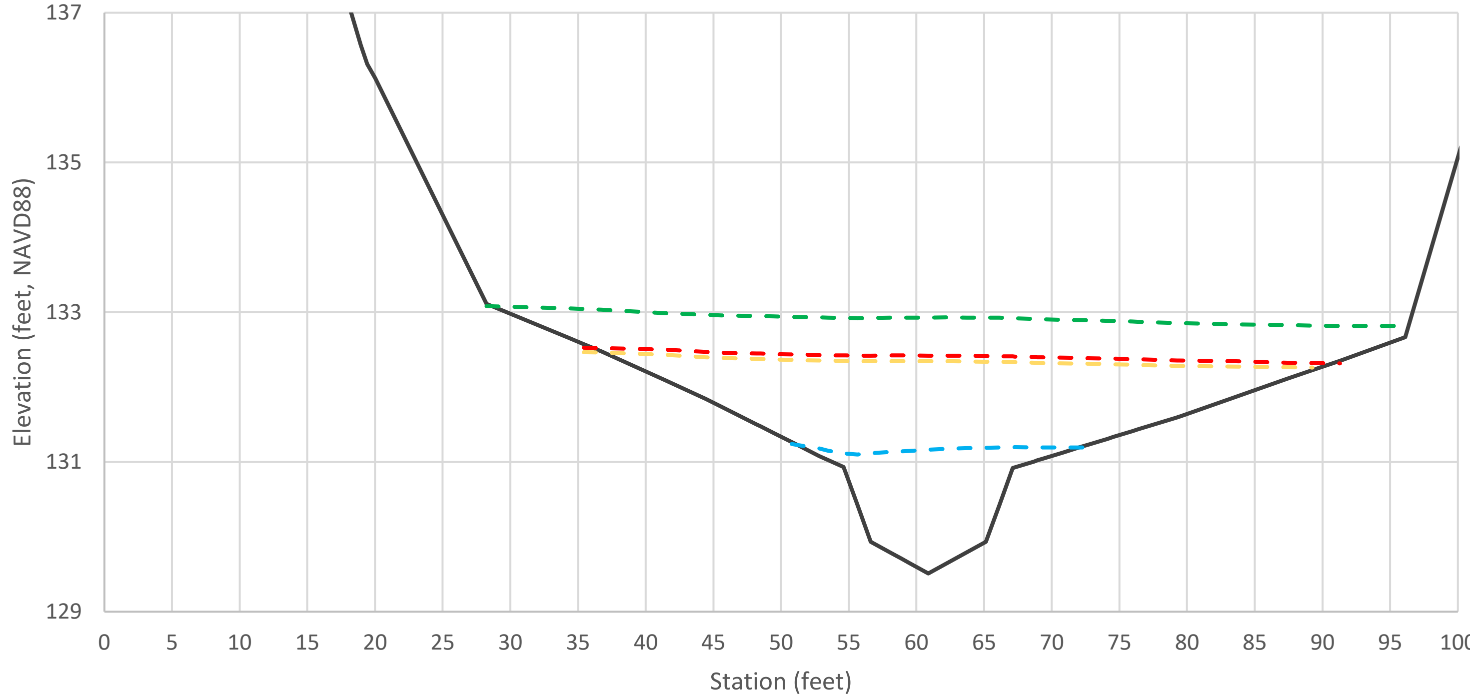
Ground — 2-yr — 100-yr — 500-yr

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
3. All cross sections are looking downstream.

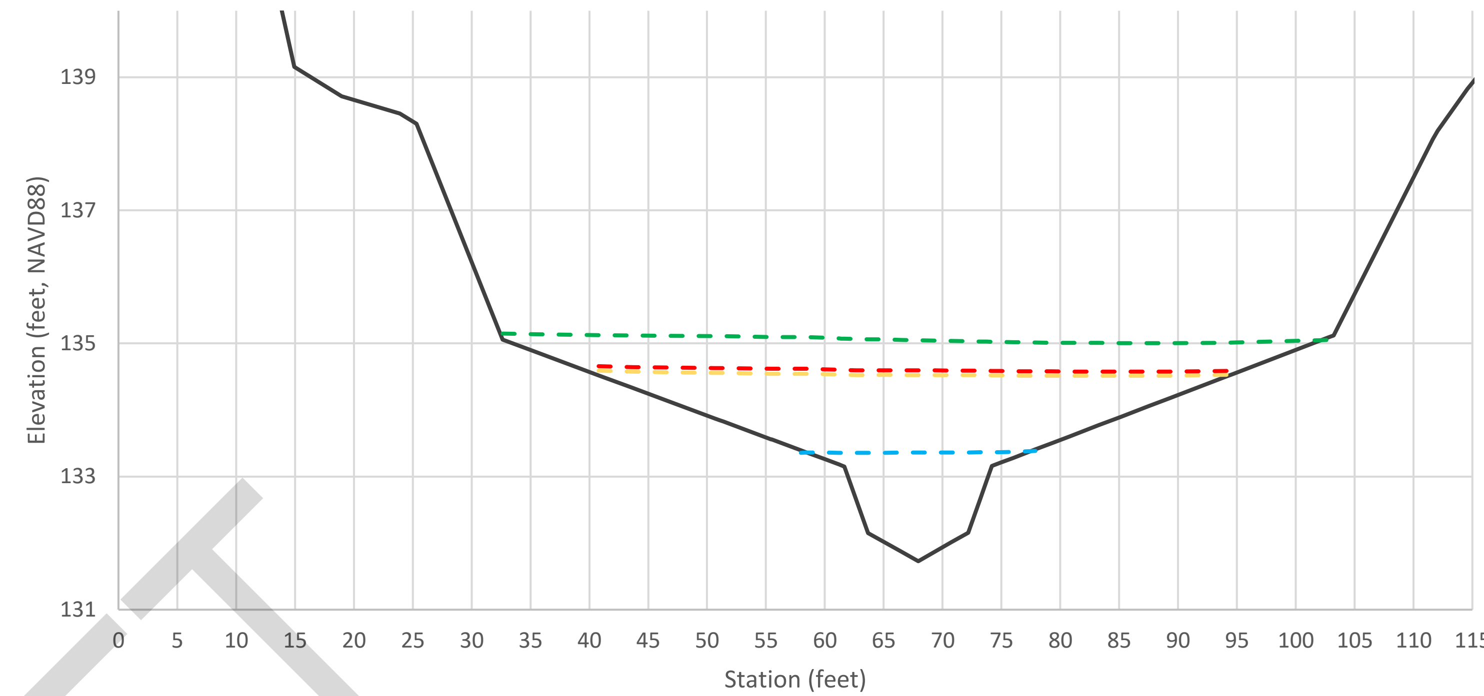
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Existing Conditions Water Surface Elevation at Cross Sections	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-7

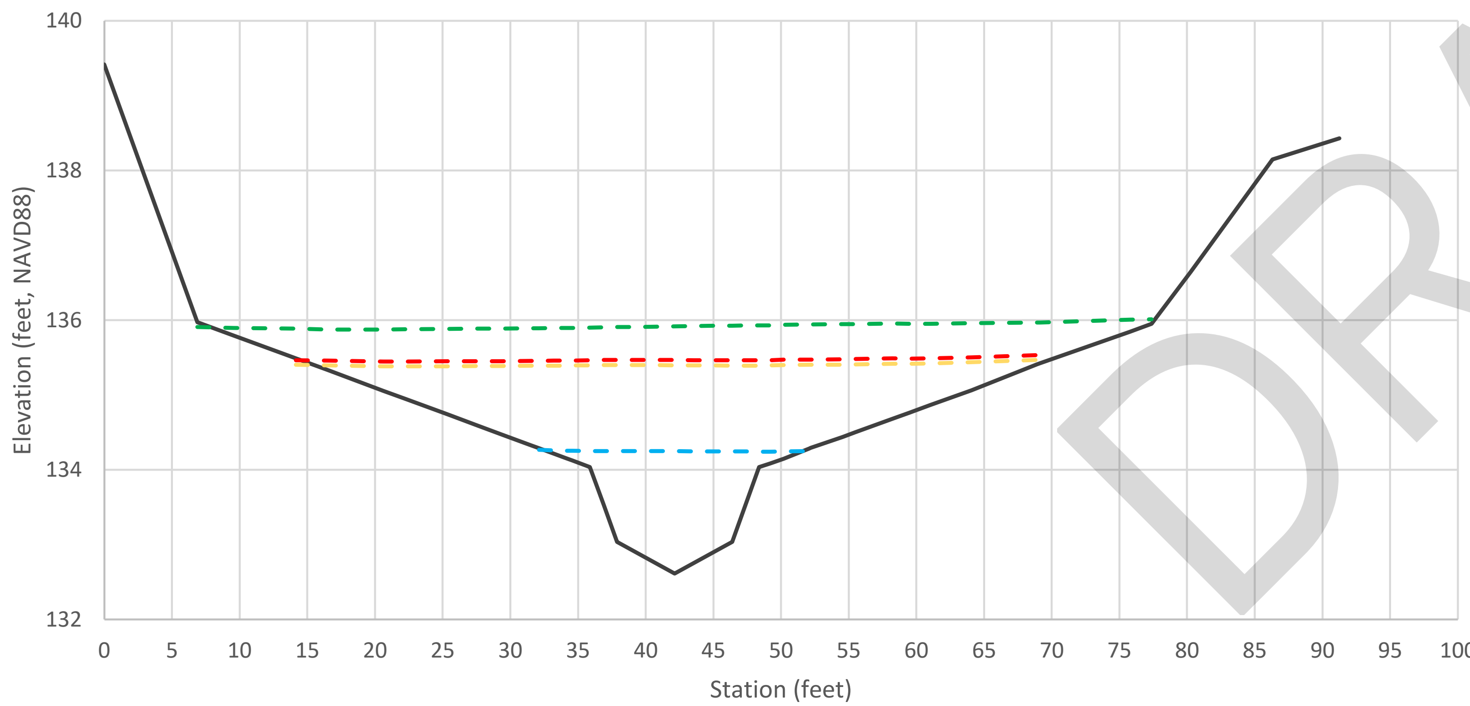
00180-406-01 Date Exported: 09-21-22



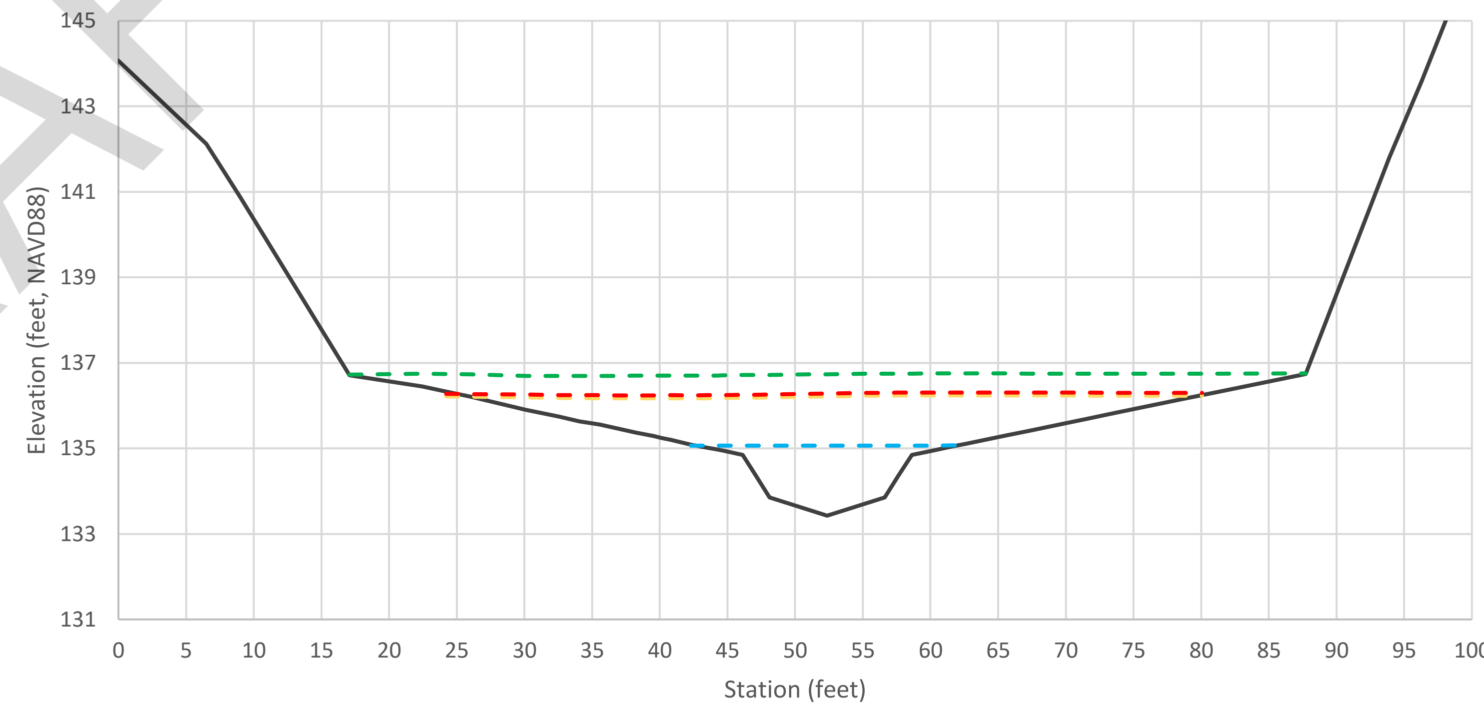
Cross Section A – Downstream STA 11+03



Cross Section B – Downstream 12+26



Cross Section C – Structure STA 12+75



Cross Section D – Upstream STA 13+19

Ground — 2-yr — 100-yr — 500-yr — 2080 100-yr

Notes:
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3. All cross sections are looking downstream.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

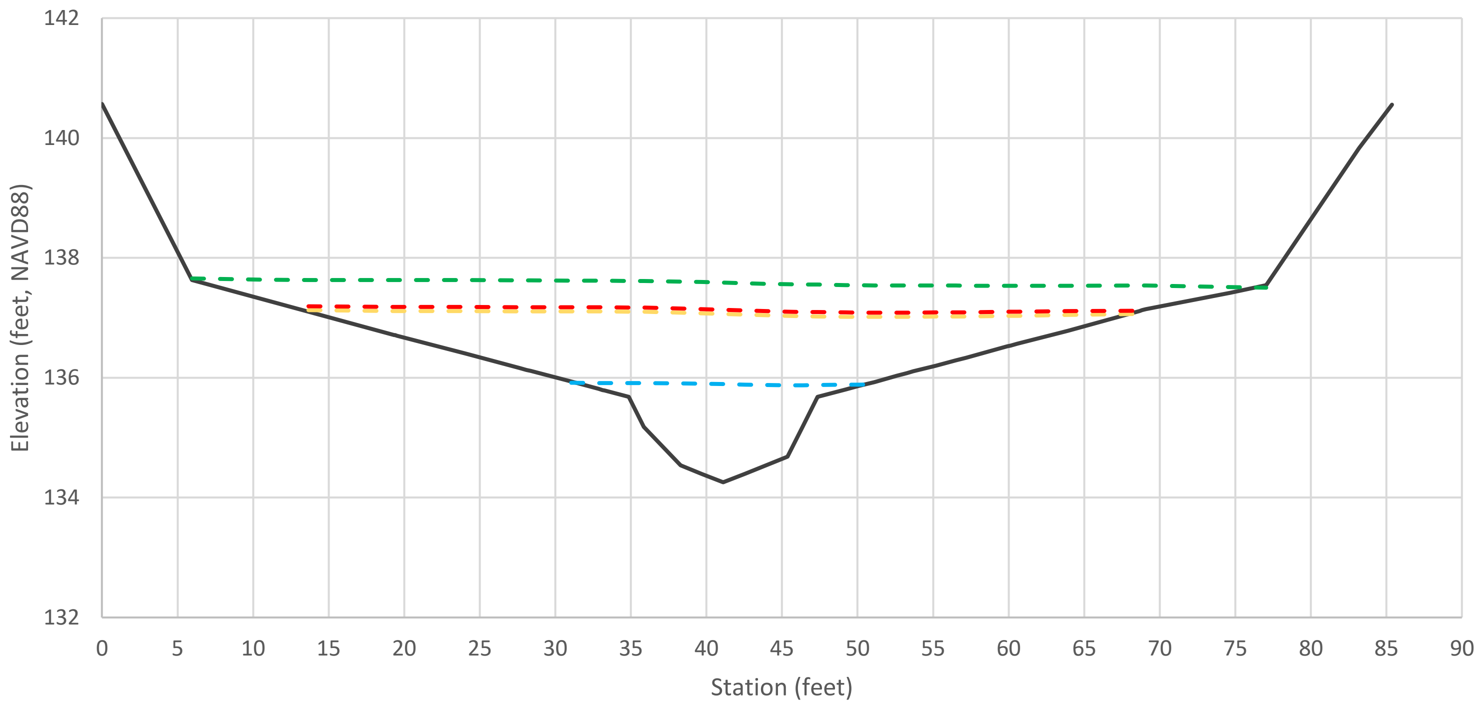
Natural Conditions
Water Surface Elevation at Cross Sections

UNT Dogfish Creek
Kitsap County

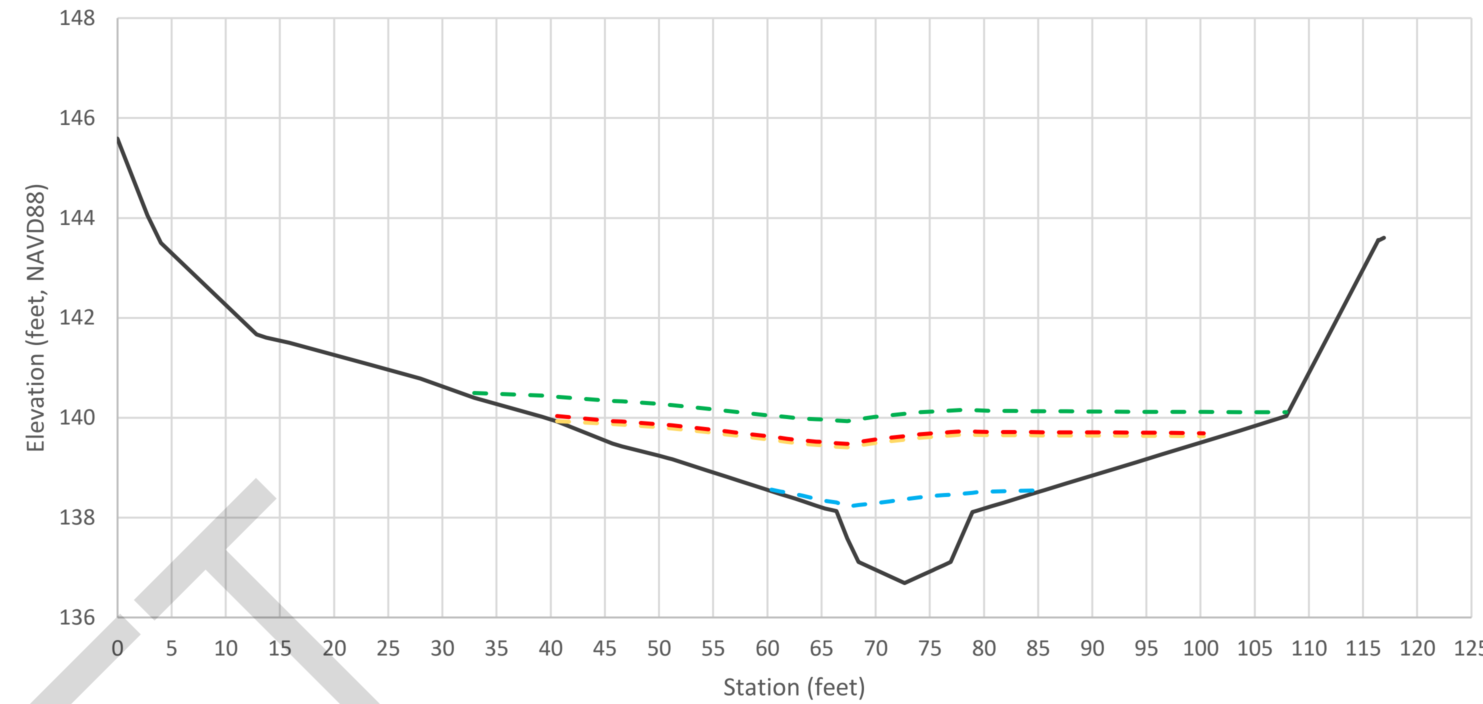
WSDOT GeoEngineers

Figure H-8

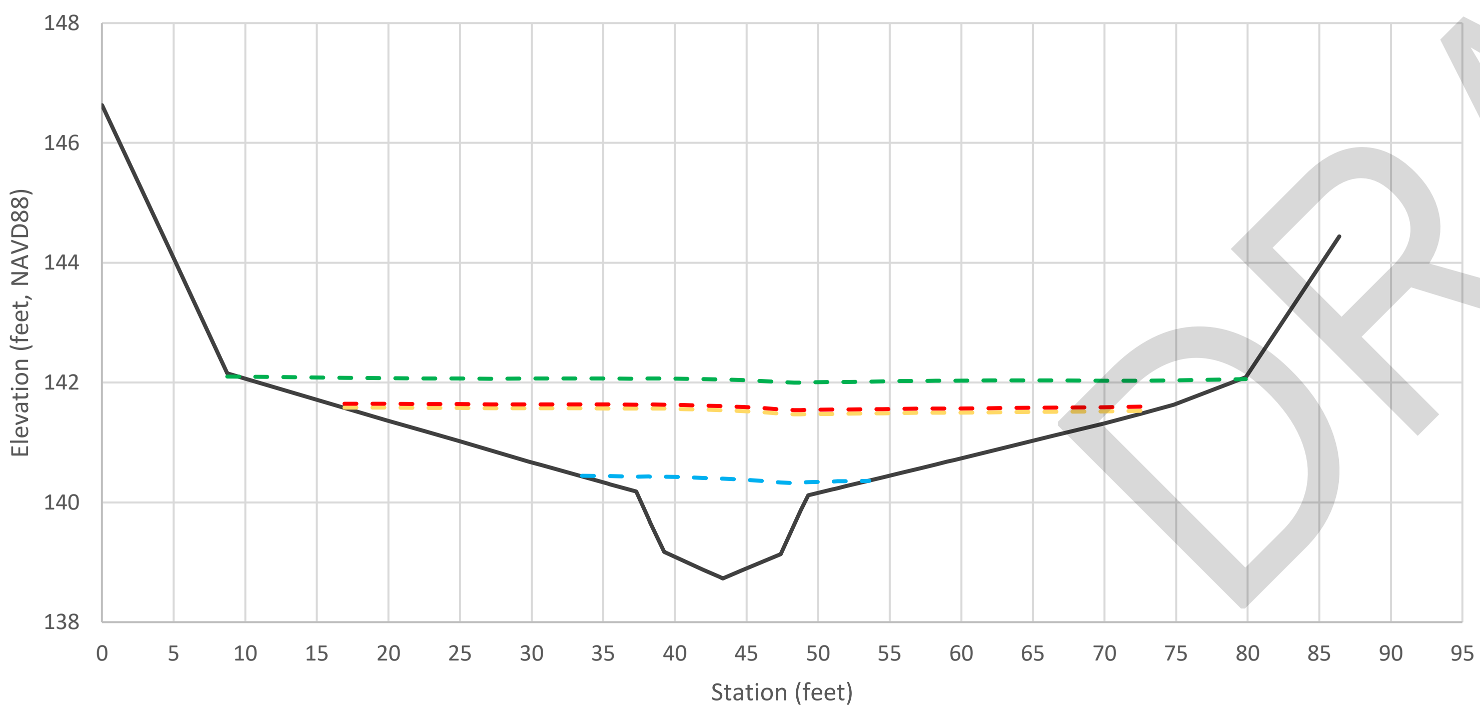
00180-406-01 Date Exported: 09-21-22



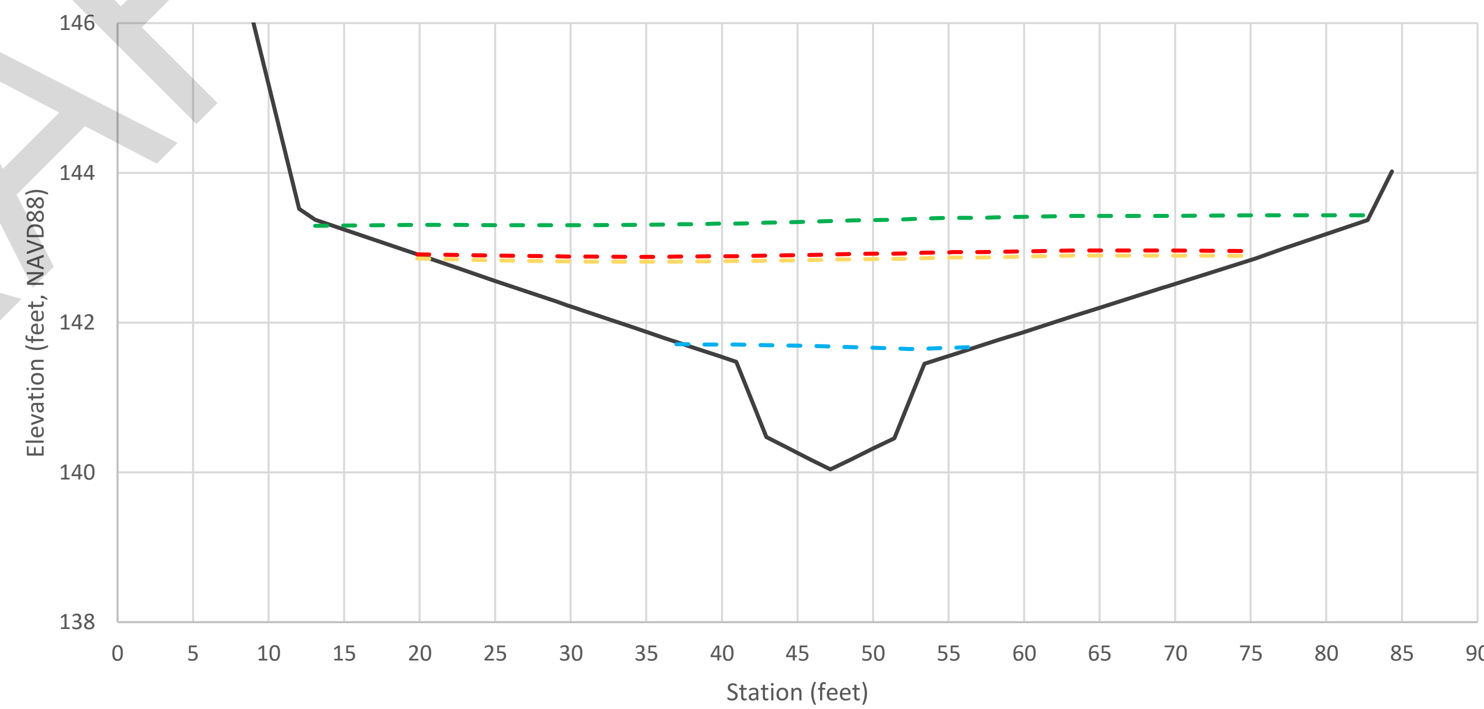
Cross Section E – Upstream 13+19



Cross Section F – Upstream 15+00



Cross Section G– Upstream 16+14



Cross Section H– Upstream 16+86

Ground — 2-yr — 100-yr — 500-yr — 2080 100-yr

Notes:
1. The locations of all features shown are approximate.
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3. All cross sections are looking downstream.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

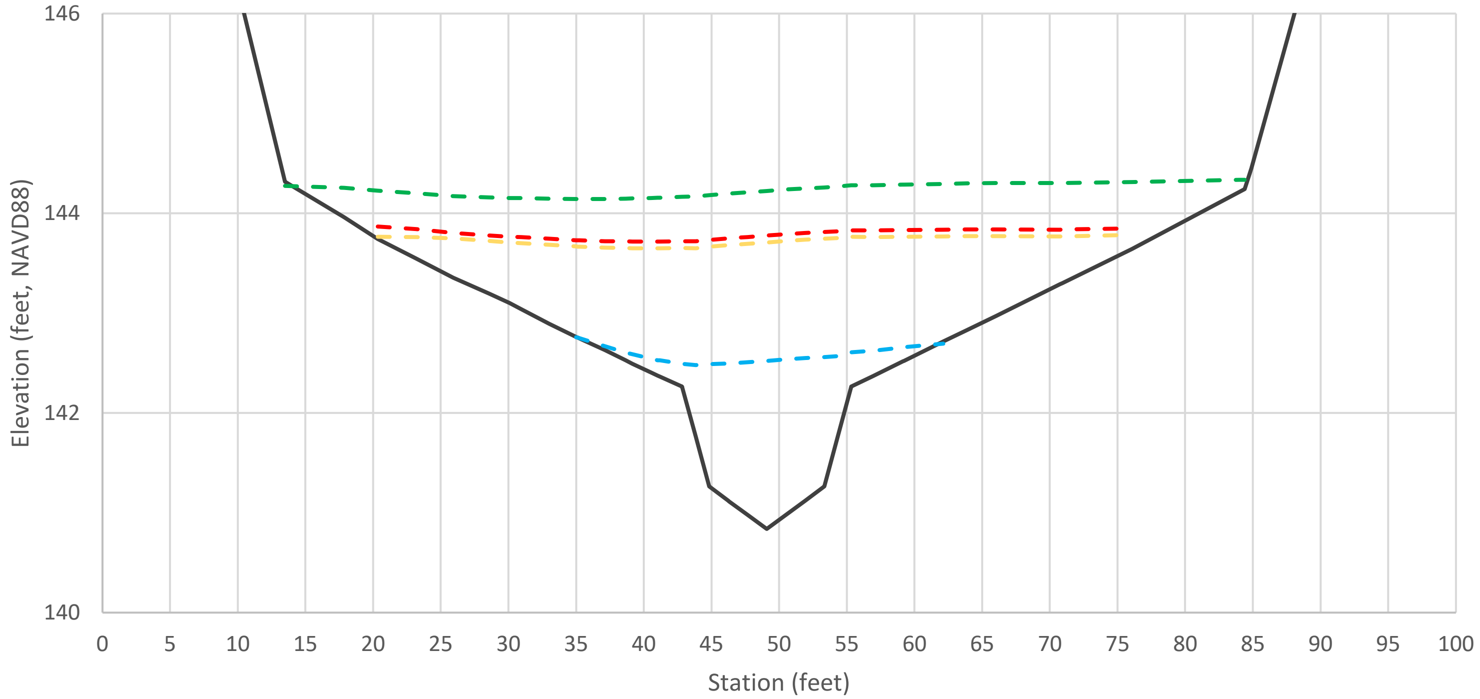
Natural Conditions
Water Surface Elevation at Cross Sections

UNT Dogfish Creek
Kitsap County

WSDOT GeoEngineers

Figure H-9

00180-406-01 Date Exported: 09-21-22



Cross Section I– Upstream 17+30

DRAFT

Ground — 2-yr — 100-yr — 500-yr — 2080 100-yr

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
3. All cross sections are looking downstream.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

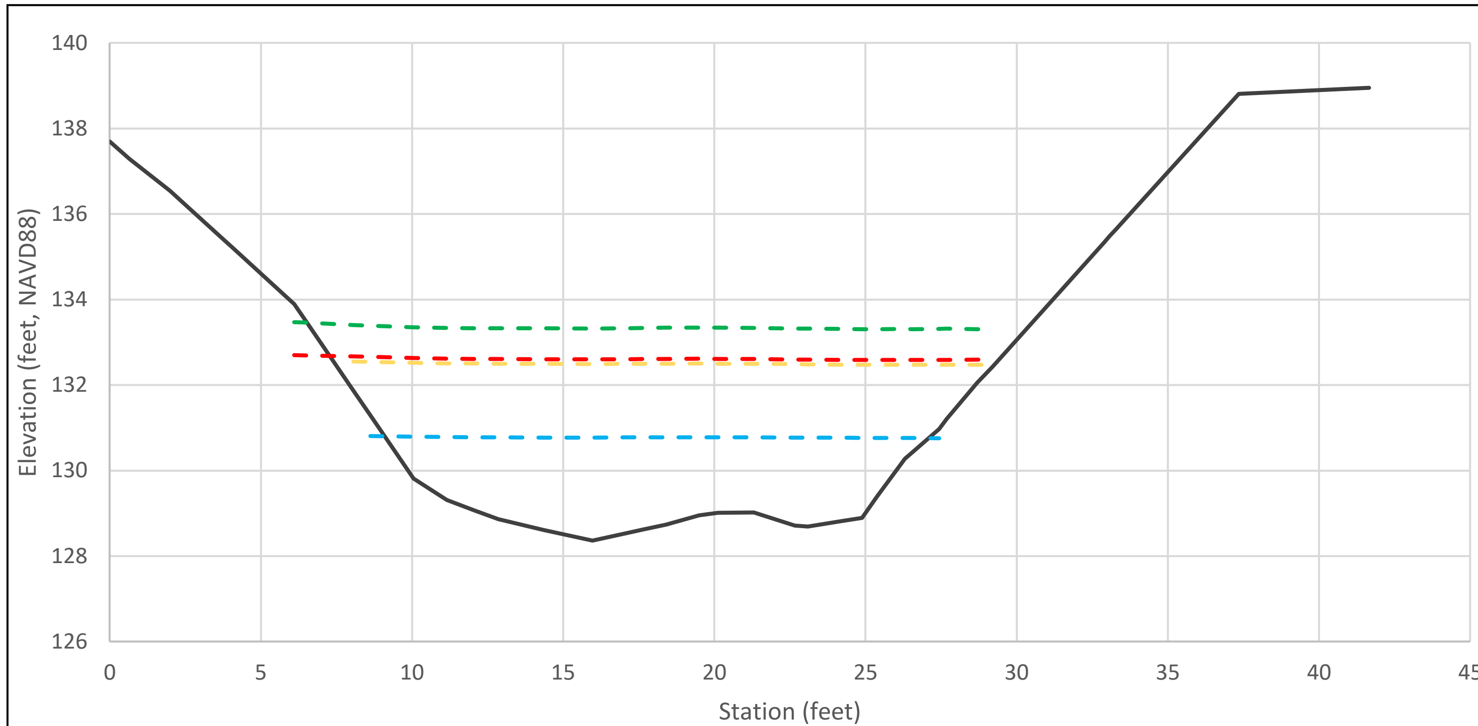
Natural Conditions
Water Surface Elevation at Cross Sections

UNT Dogfish Creek
Kitsap County

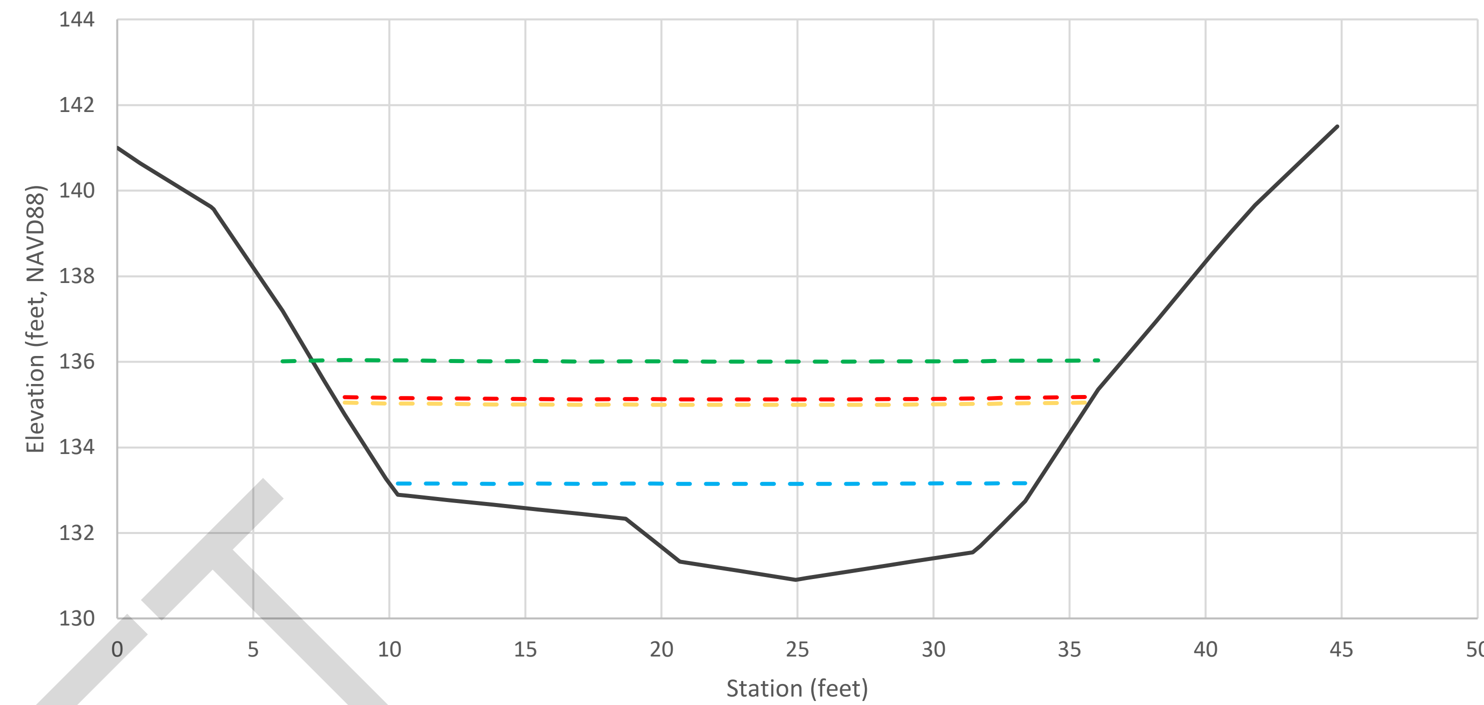
WSDOT GeoEngineers

Figure H-10

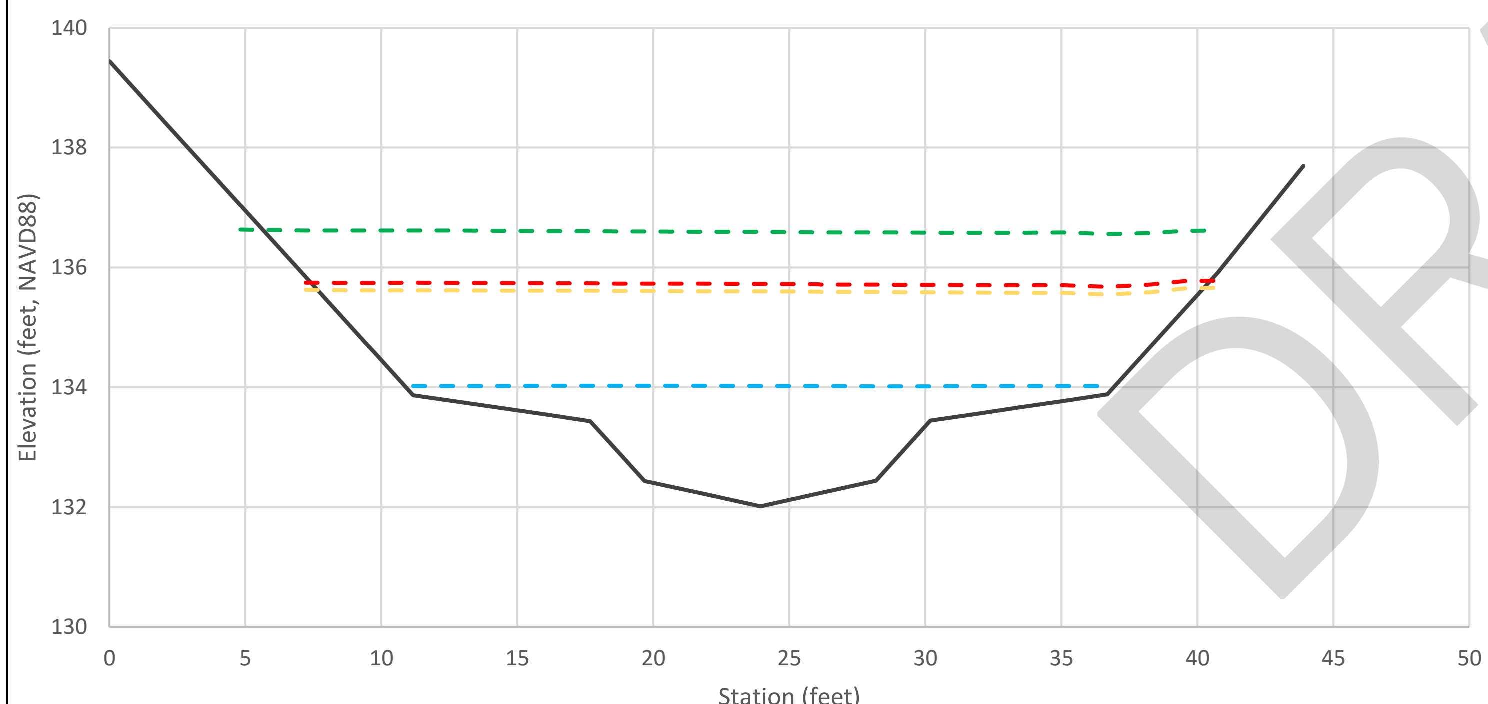
00180-406-01 Date Exported: 09-21-22



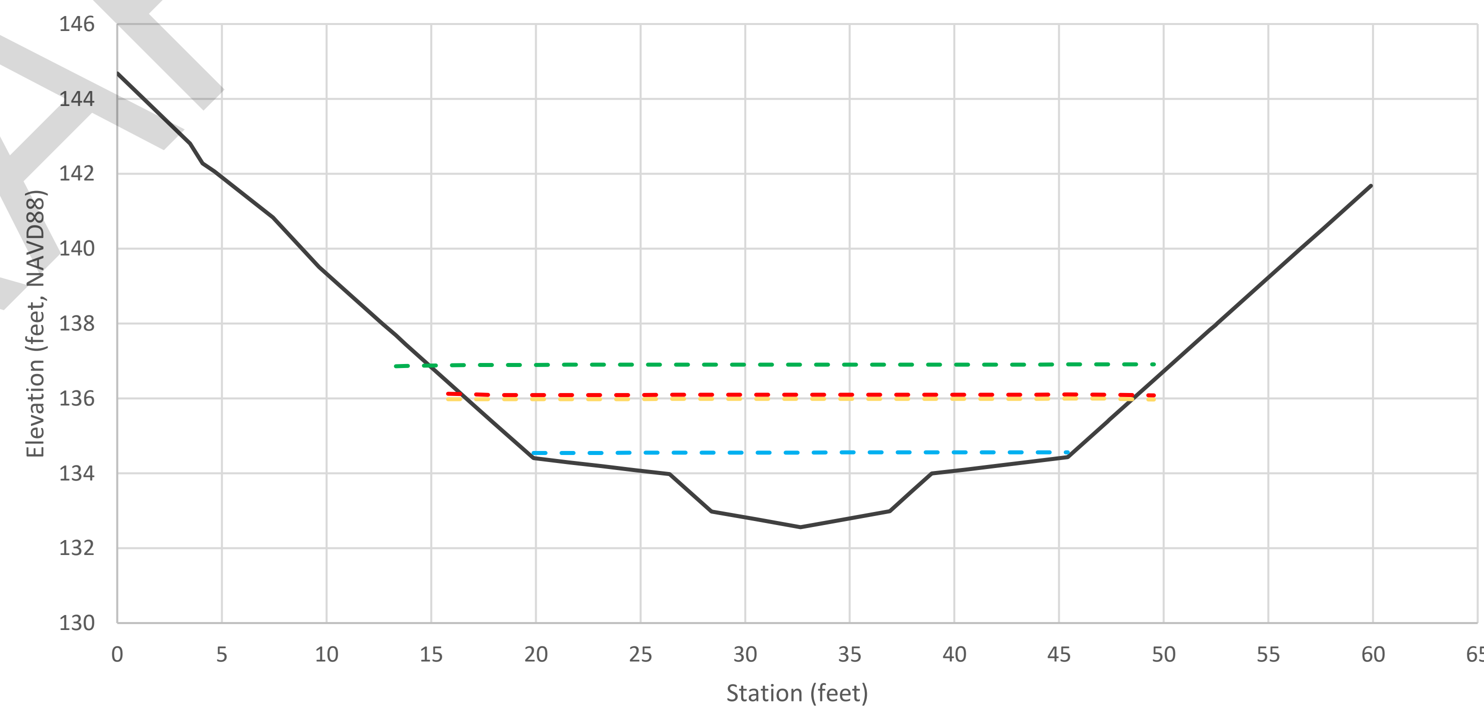
Cross Section A – Downstream STA 11+03



Cross Section B – Downstream STA 12+26



Cross Section C – Downstream STA 12+78



Cross Section D – Structure STA 13+03

Ground 2-yr 100-yr 500-yr 2080 100-yr

Notes:
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3. All cross sections are looking downstream.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

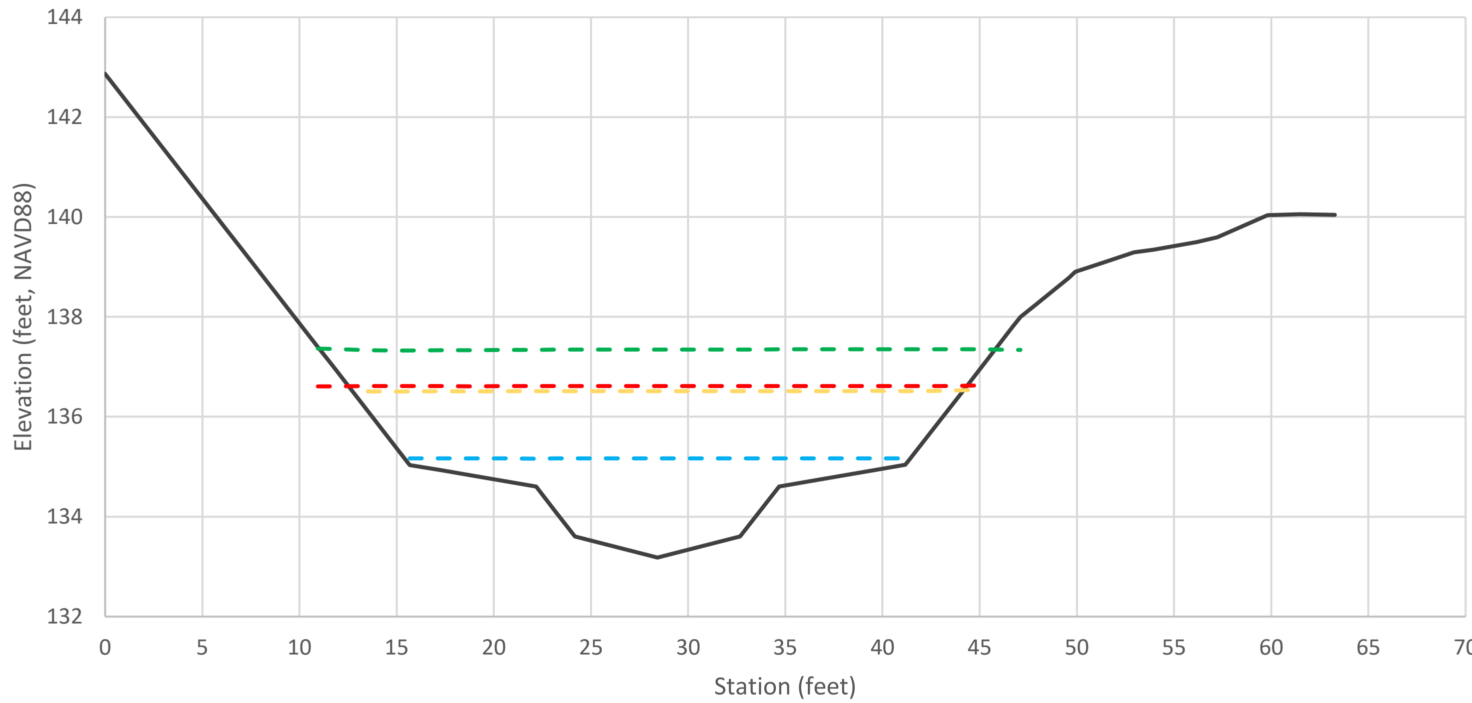
Proposed Conditions
Water Surface Elevation at Cross Sections

UNT Dogfish Creek
Kitsap County

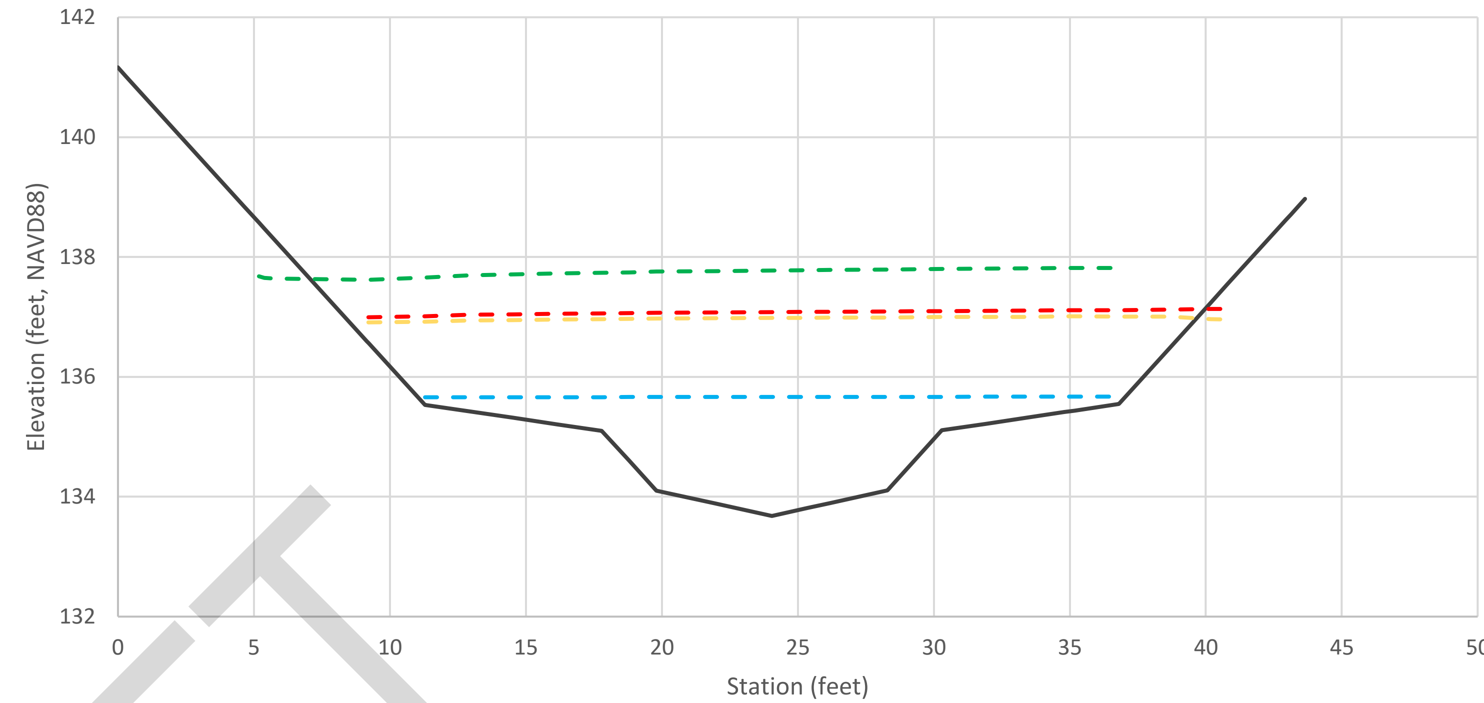
WSDOT GeoEngineers

Figure H-11

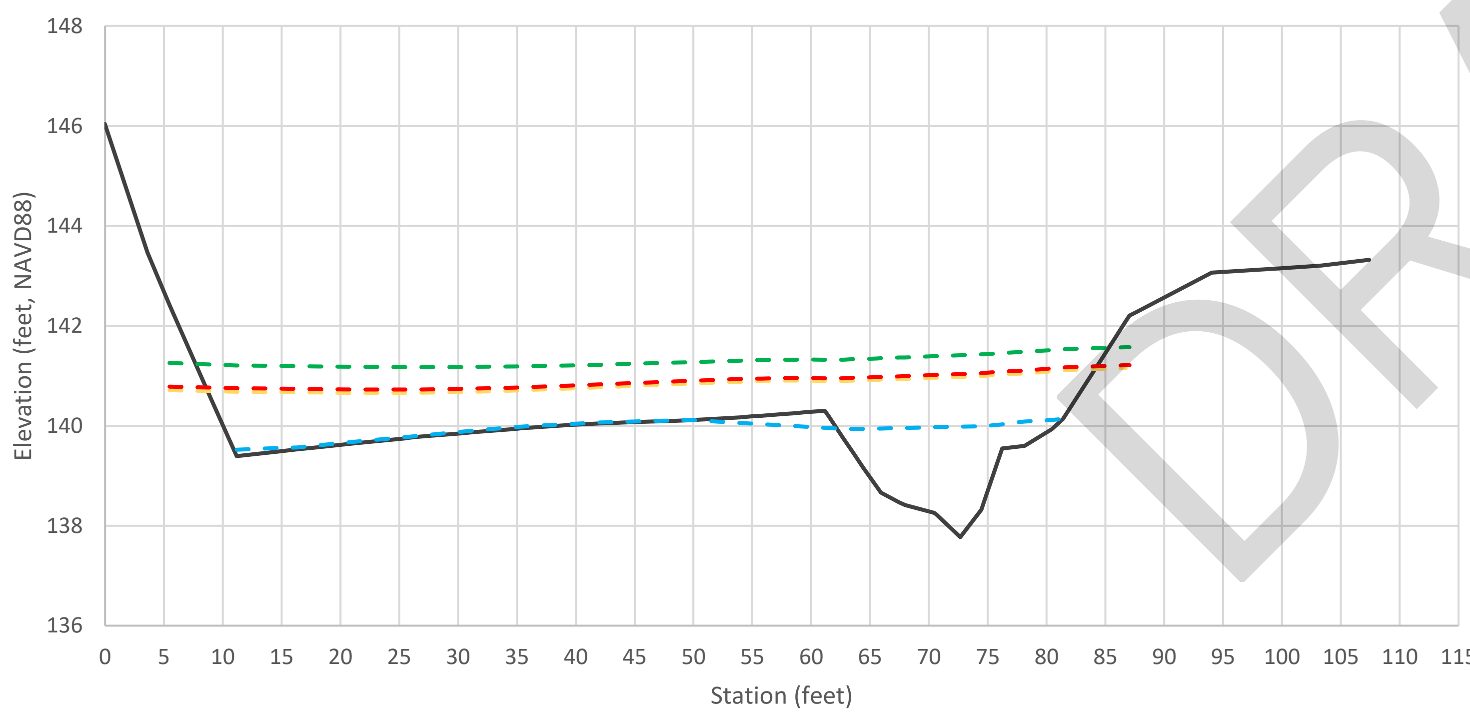
00180-406-01 Date Exported: 09-21-22



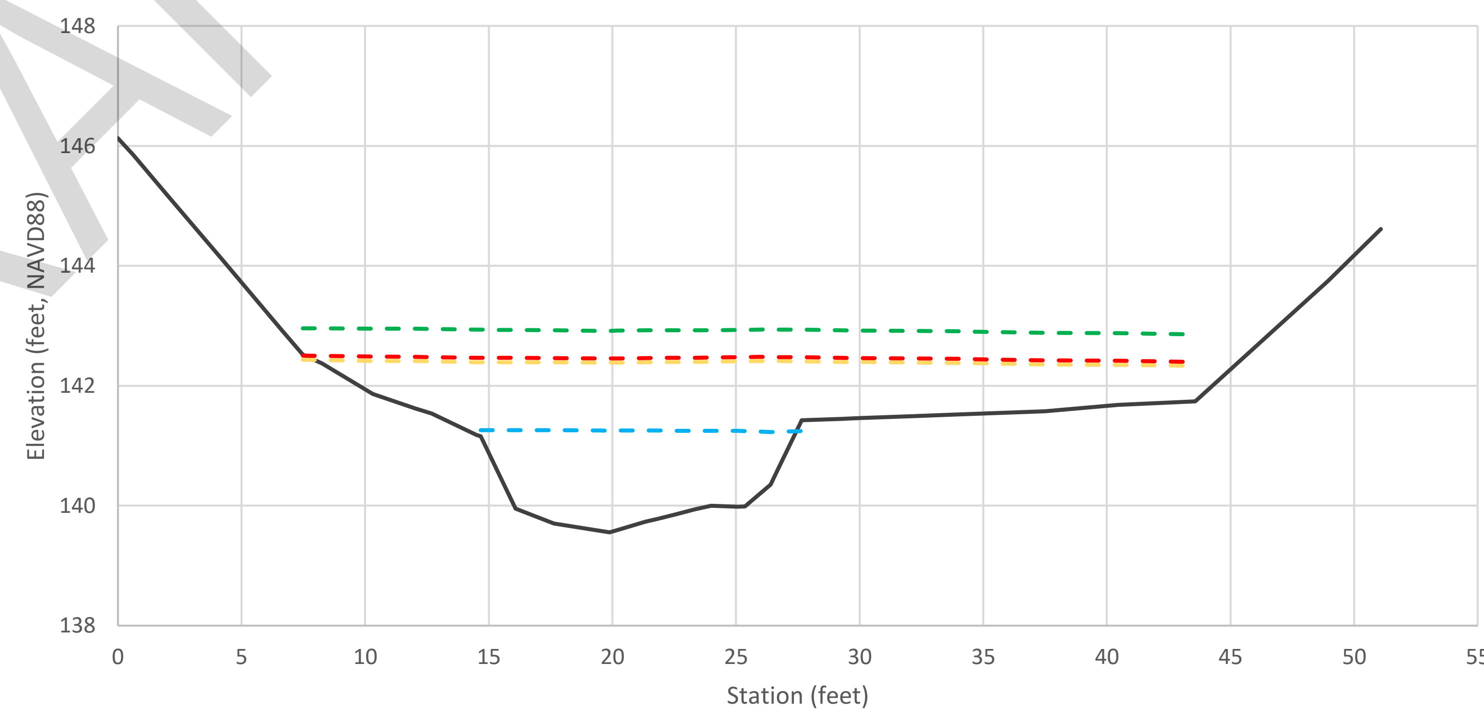
Cross Section E – Upstream STA 13+31



Cross Section F – Upstream STA 13+56



Cross Section G – Upstream 15+20



Cross Section H – Upstream 16+33

Ground — 2-yr — 100-yr — 500-yr — 2080 100-yr

Notes:
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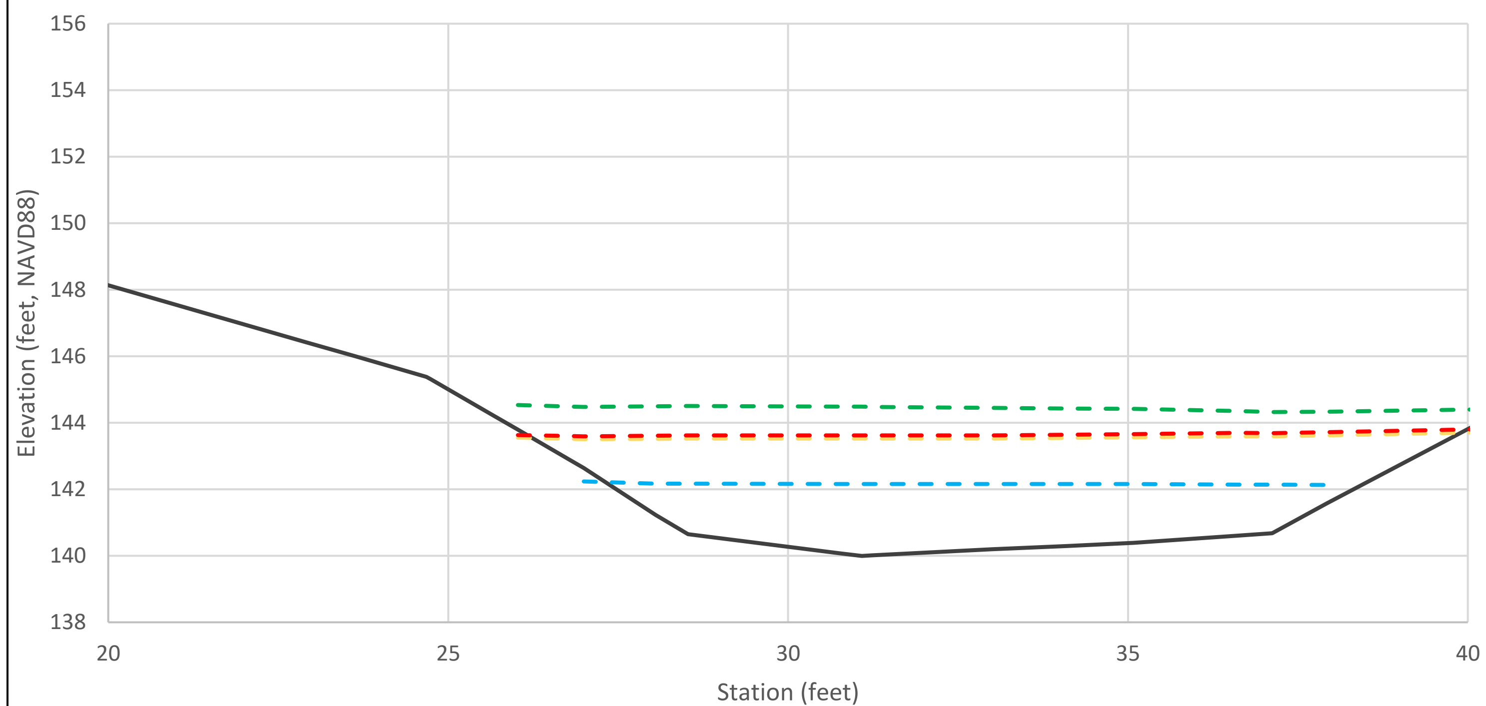
3. All cross sections are looking downstream.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Proposed Conditions Water Surface Elevation at Cross Sections
UNT Dogfish Creek Kitsap County
WSDOT GeoEngineers — **Figure H-12**

00180-406-01 Date Exported: 09-21-22



Cross Section I – Upstream STA 17+05

Notes:
1. The locations of all features shown are approximate.
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3. All cross sections are looking downstream.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

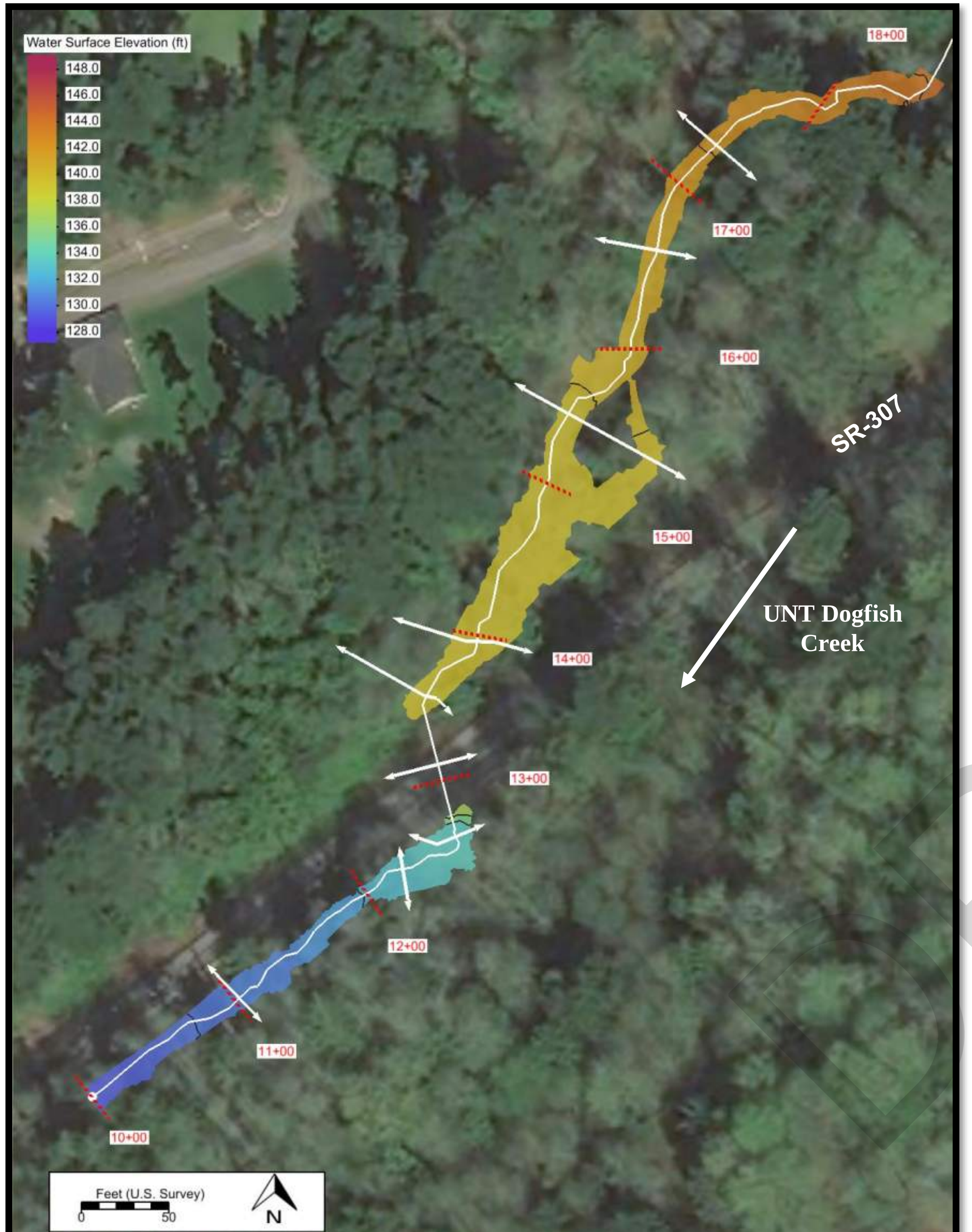
Proposed Conditions
Water Surface Elevation at Cross Sections

UNT Dogfish Creek
Kitsap County

WSDOT GeoEngineers

Figure H-13

00180-406-01 Date Exported: 09-21-22



Water Surface Elevation (FT NAVD88)

Velocity (FT/S)

Existing Conditions Plan Views 2-year Event (61.5 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-14

Notes:

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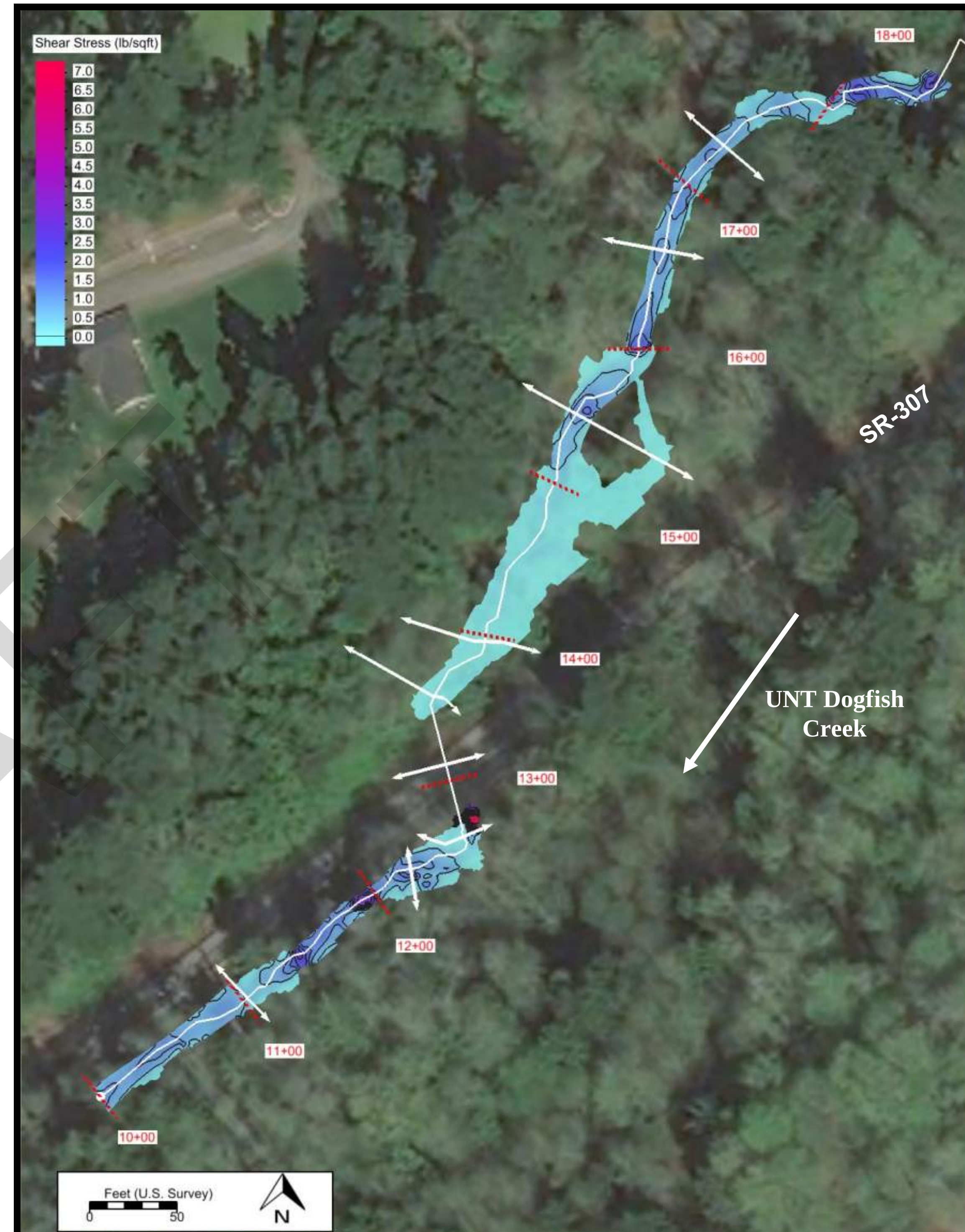
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Depth (FT)



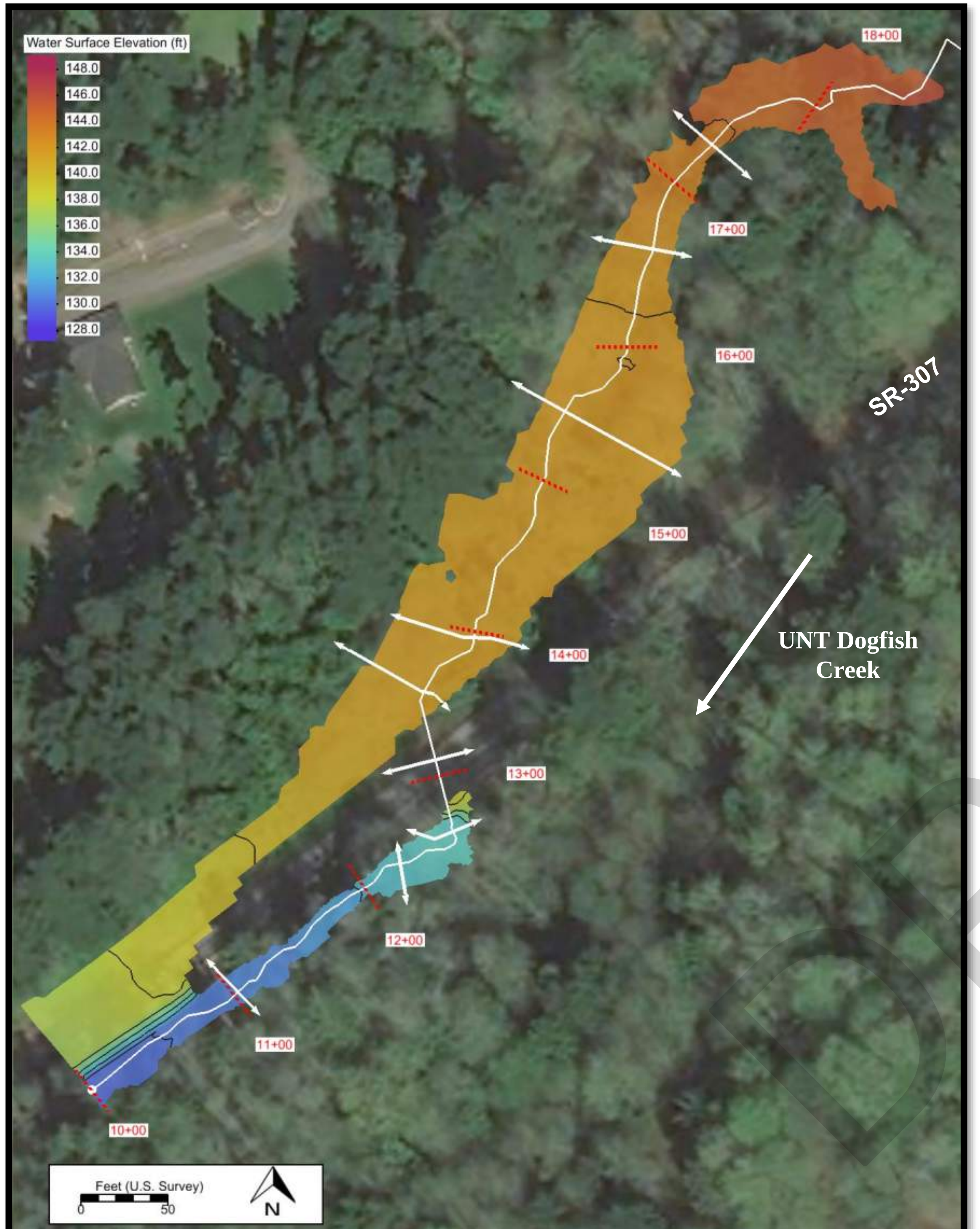
Shear Stress (LB/SF)

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

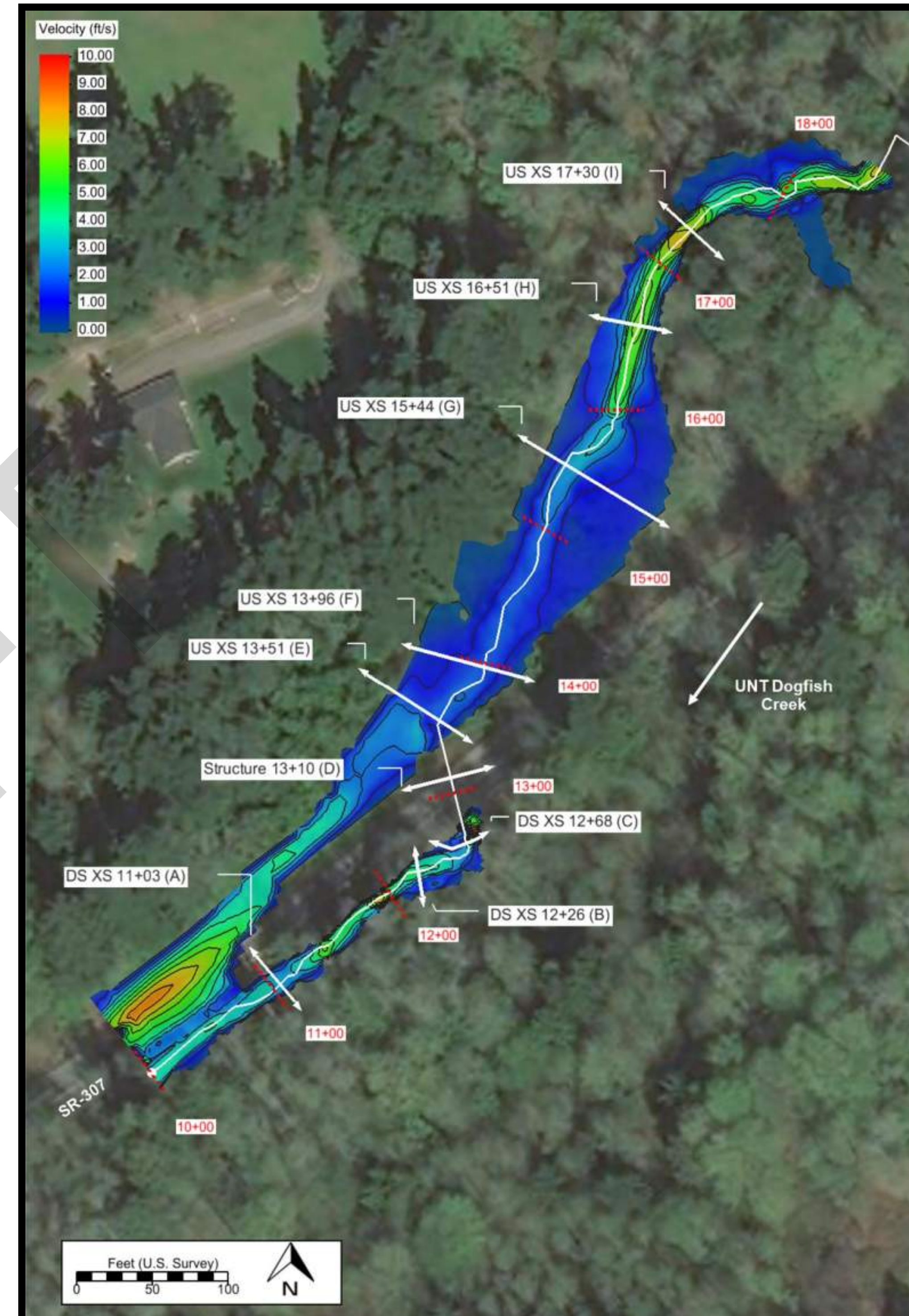
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Existing Conditions Plan Views 2-year Event (61.5 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-15

00180-406-01 Date Exported: 09-21-22



Water Surface Elevation (FT NAVD88)



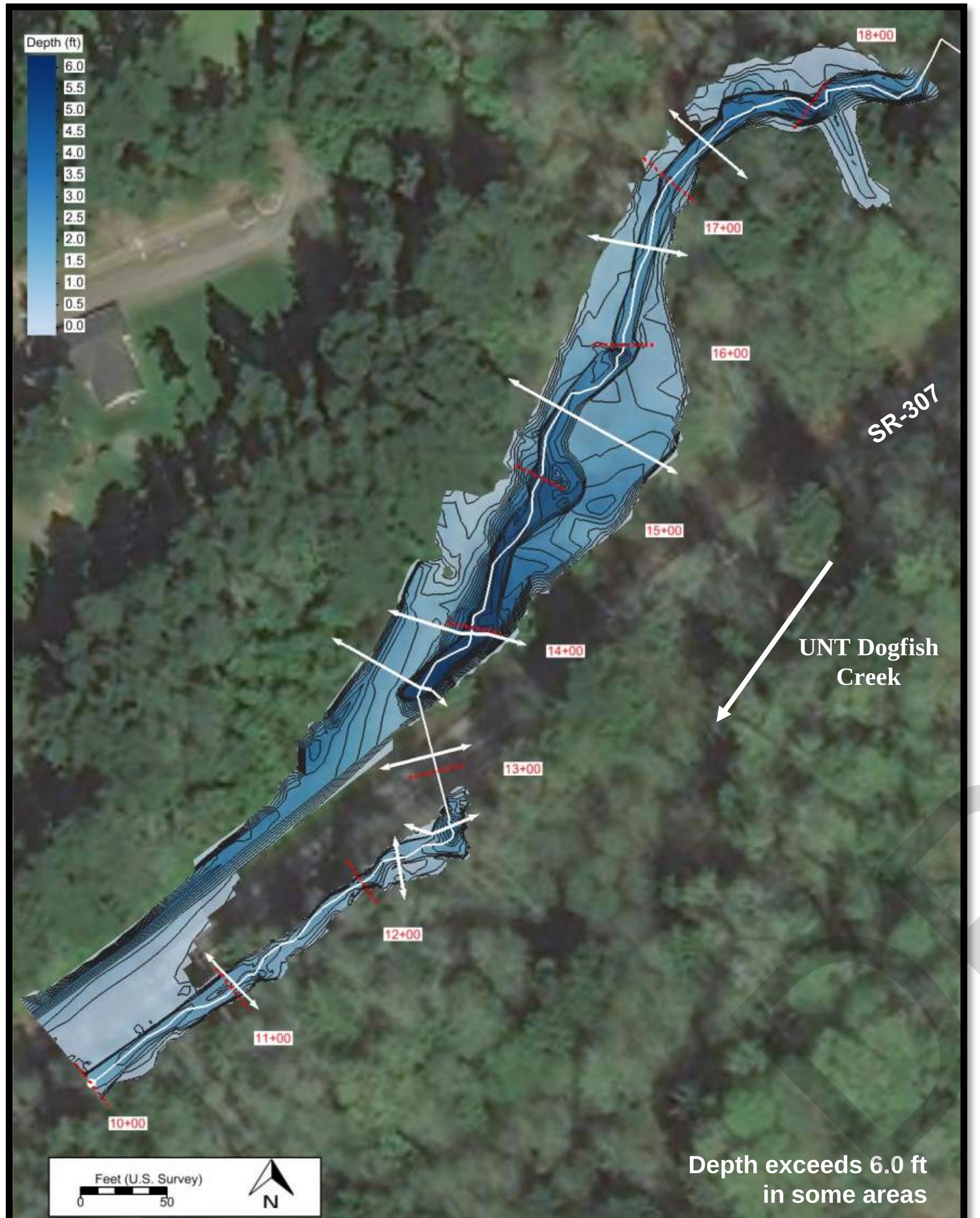
Velocity (FT/S)

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

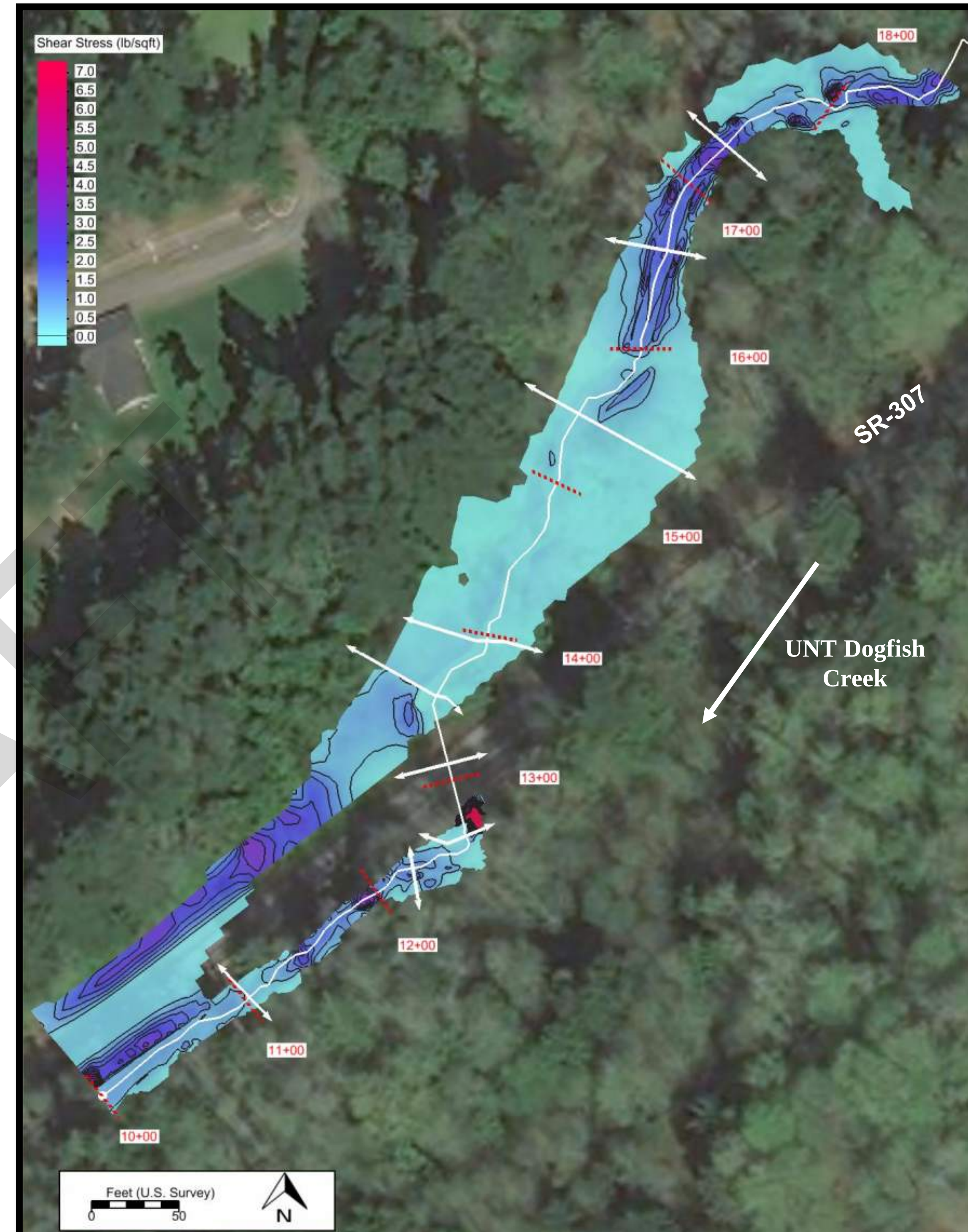
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Existing Conditions Plan Views 100-year Event (218.8 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-16

00180-406-01 Date Exported: 09-21-22



Depth (FT)



Shear Stress (LB/SF)

Notes:

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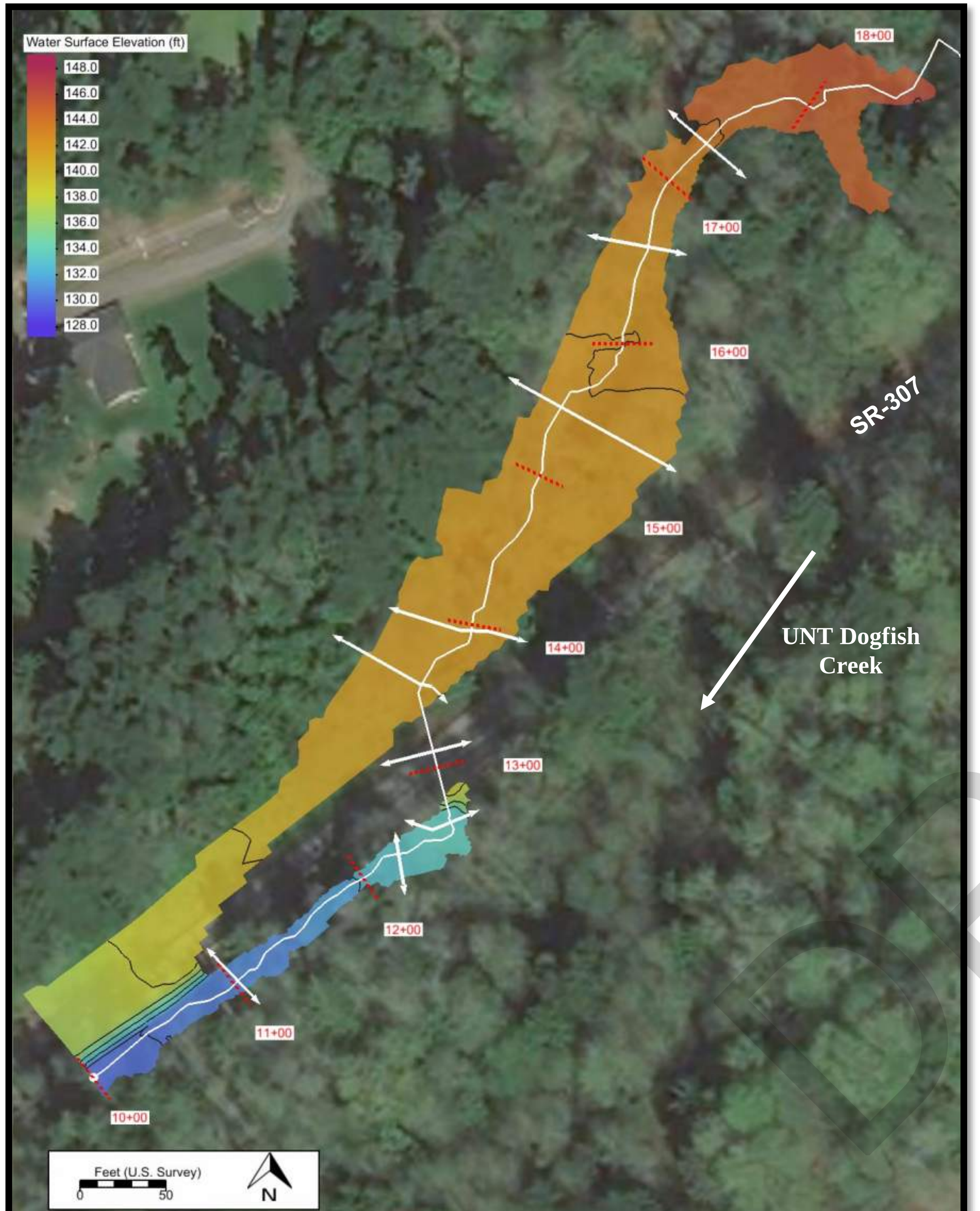
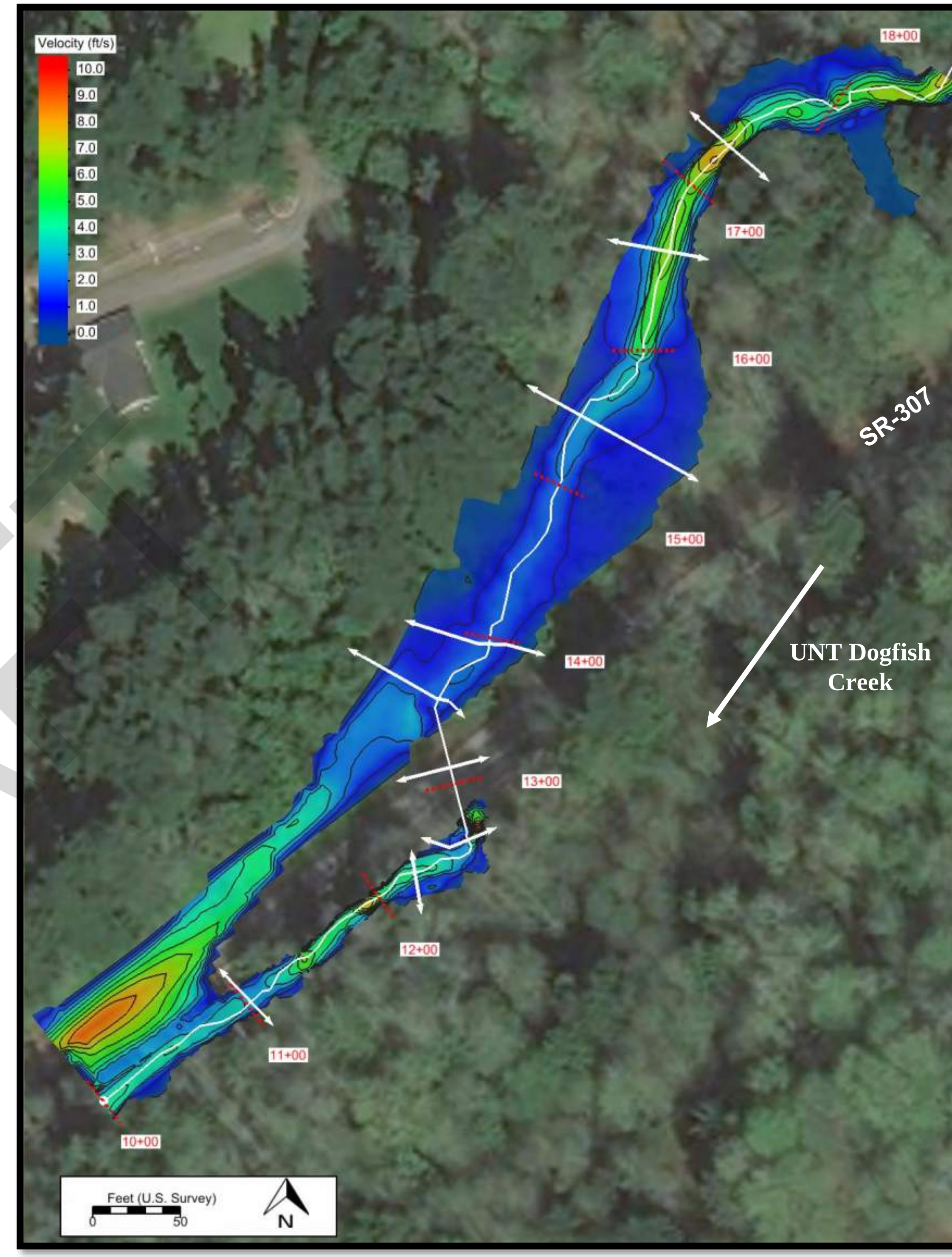
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Existing Conditions Plan Views 100-year Event (218.8 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-17



Water Surface Elevation (FT NAVD88)



Velocity (FT/S)

Existing Conditions Plan Views 500-year Event (234.1 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-18

Notes:

1. The locations of all features shown are approximate.
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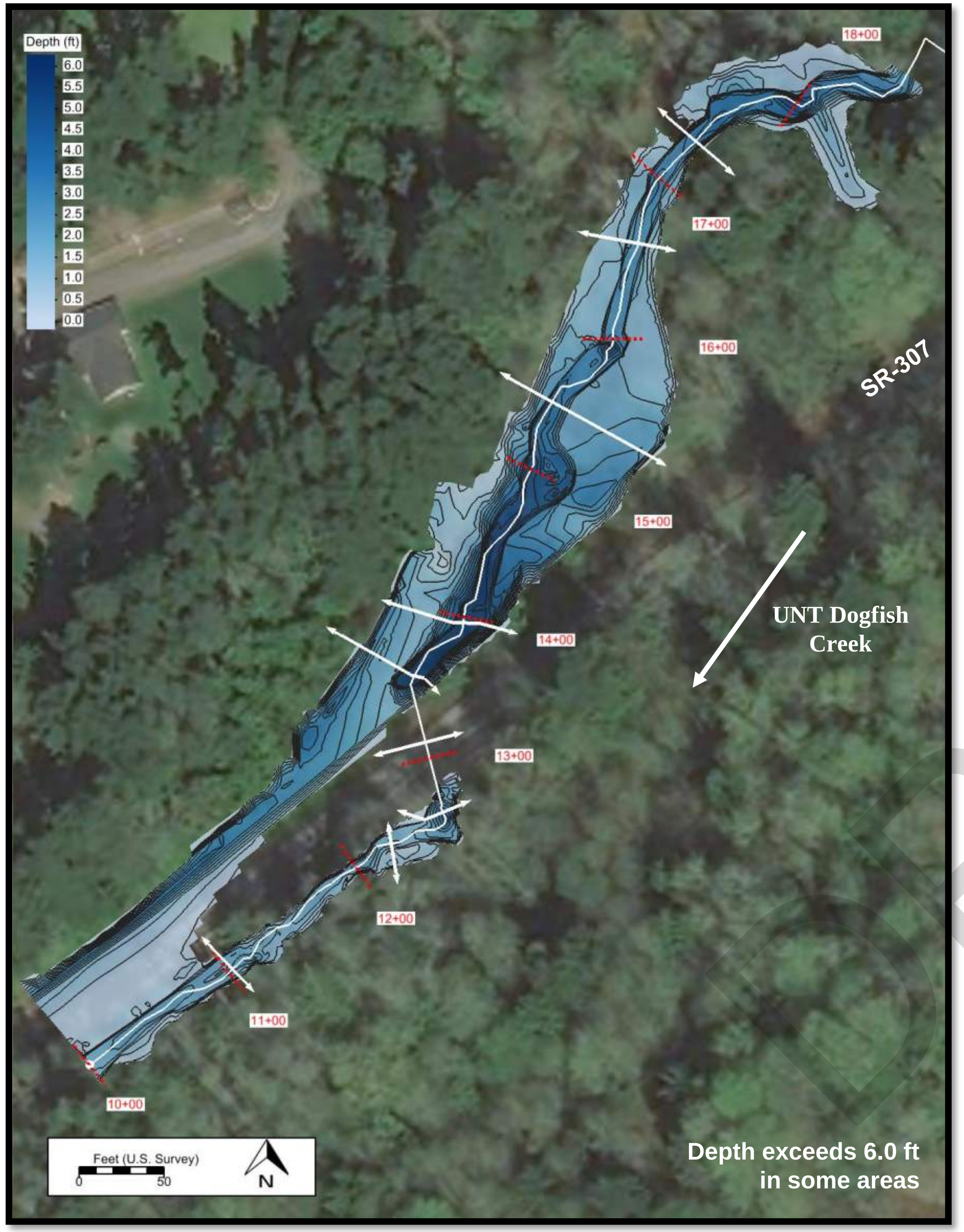
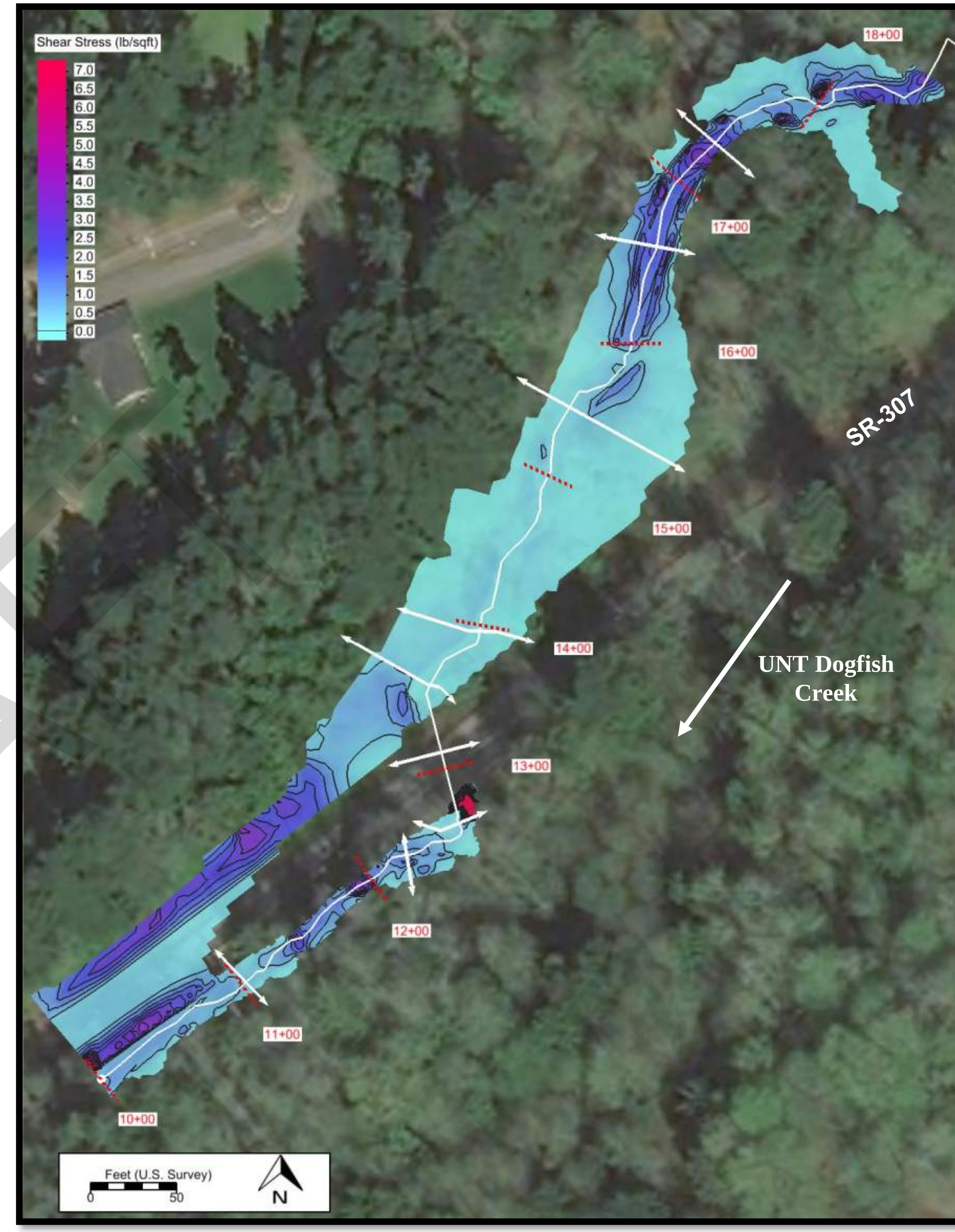
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022



Depth (FT)



Shear Stress (LB/SF)

Existing Conditions Plan Views 500-year Event (234.1 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-19

Notes:

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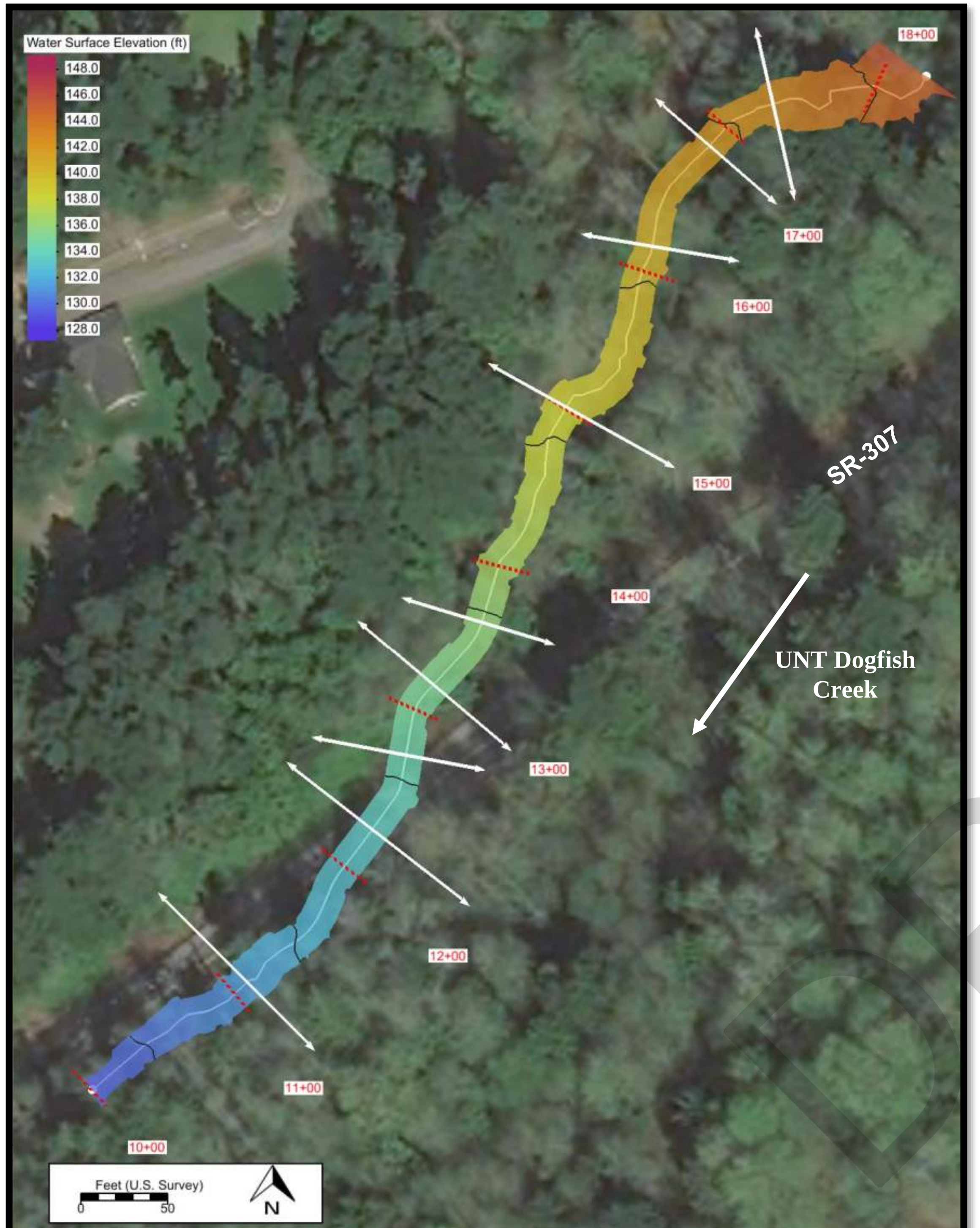
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

00180-406-01 Date Exported: 09-21-22



Water Surface Elevation (FT NAVD88)

Velocity (FT/S)

Notes:

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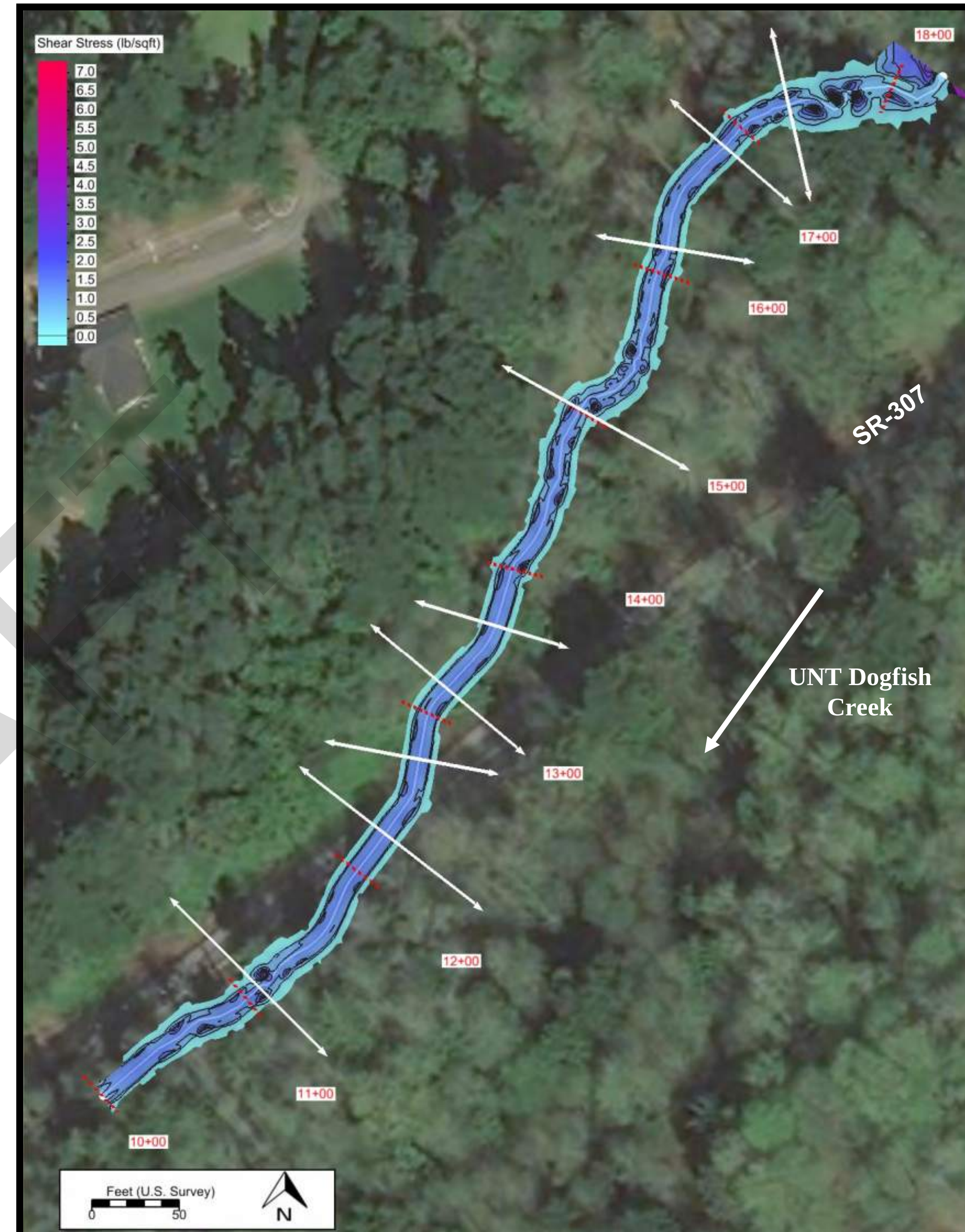
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Natural Conditions Plan Views 2-year Event (61.5 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-20

00180-406-01 Date Exported: 09-21-22

Depth (FT)



Shear Stress (LB/SF)

Natural Conditions Plan Views 2-year Event (61.5 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-21

Notes:
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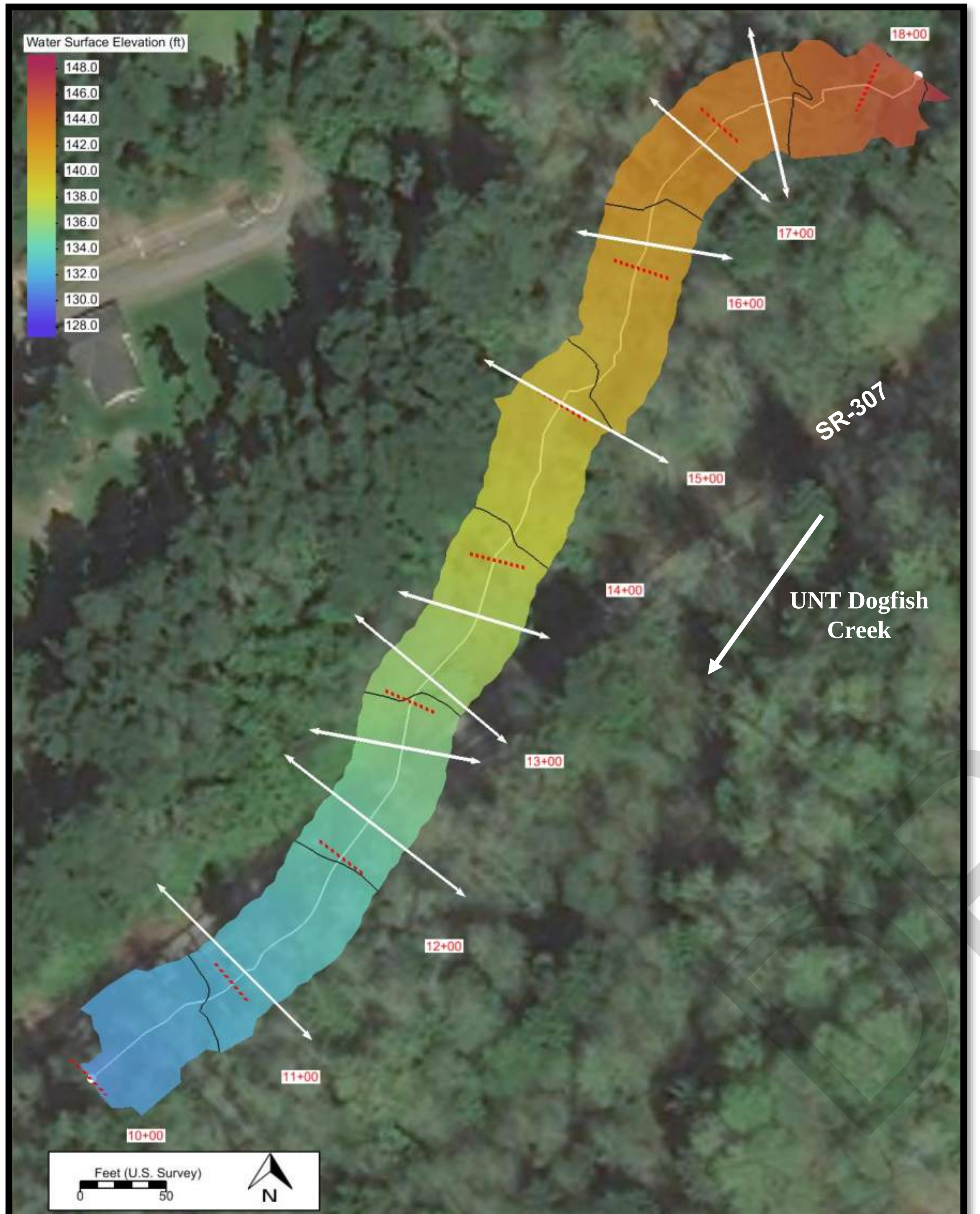
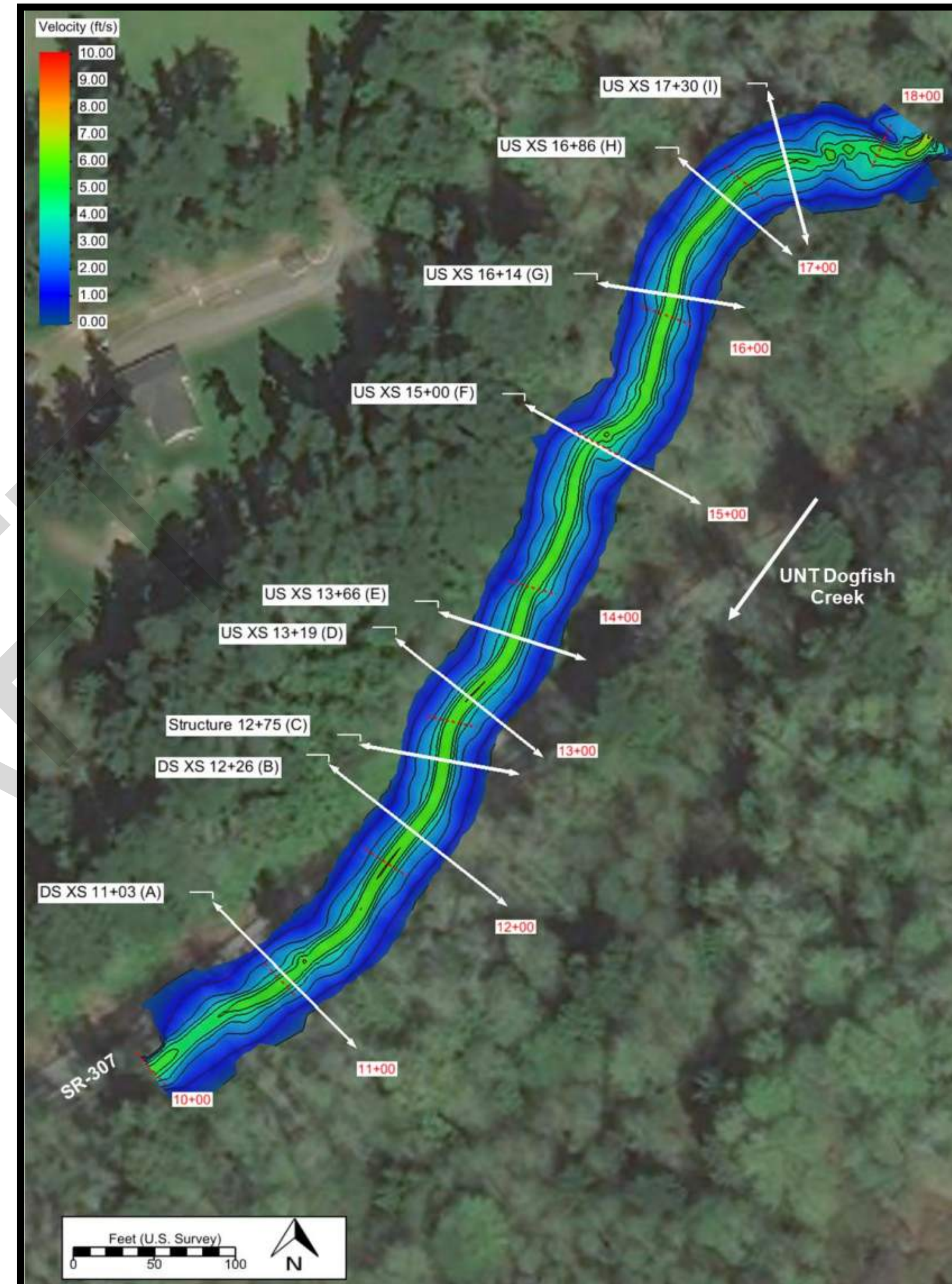
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

00180-406-01 Date Exported: 09-21-22



Water Surface Elevation (FT NAVD88)



Velocity (FT/S)

Natural Conditions Plan Views 100-year Event (218.8 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-22

Notes:

1. The locations of all features shown are approximate.
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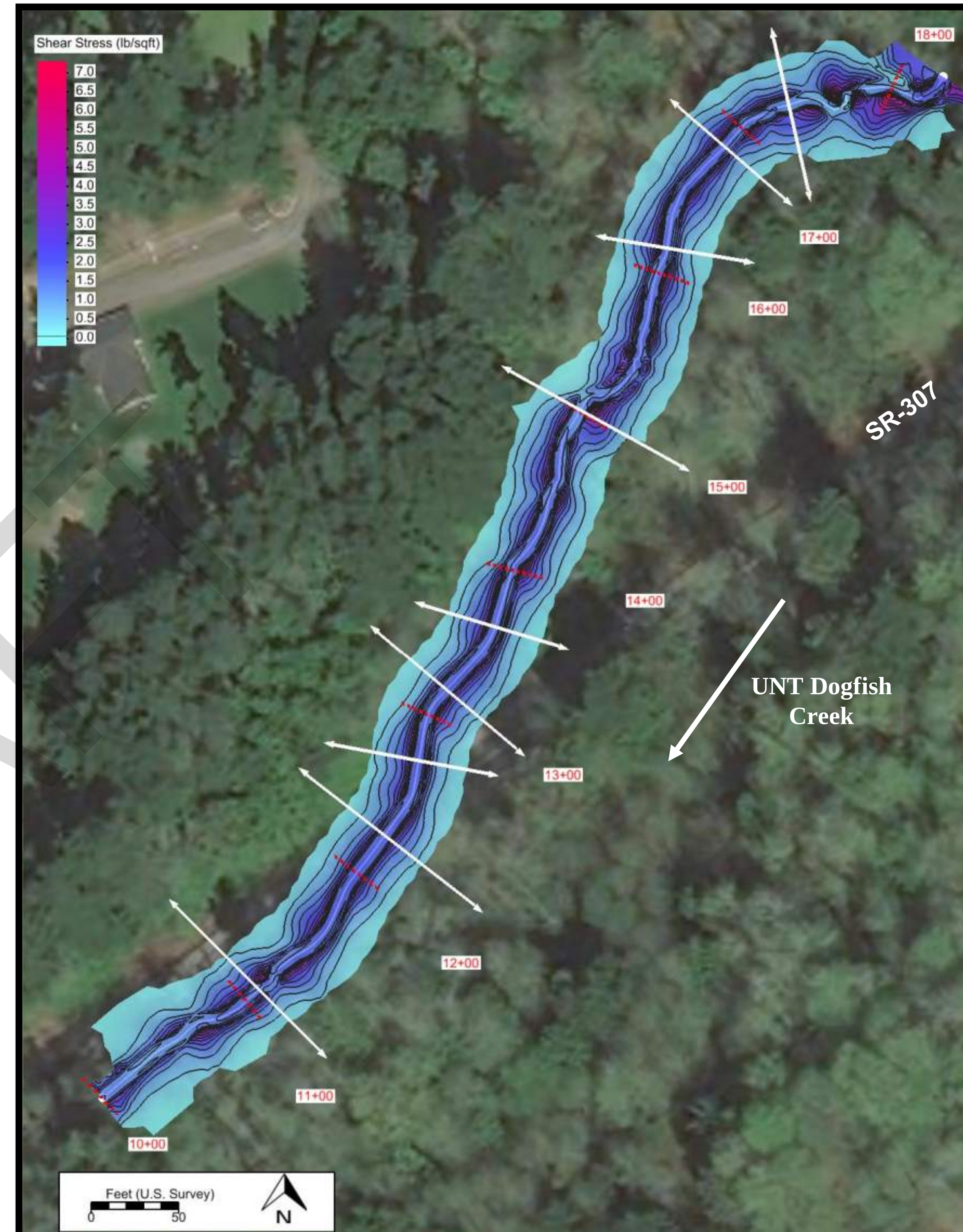
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

00180-406-01 Date Exported: 09-21-22

Depth (FT)



Shear Stress (LB/SF)

Natural Conditions Plan Views 100-year Event (218.8 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-23

Notes:

1. The locations of all features shown are approximate.
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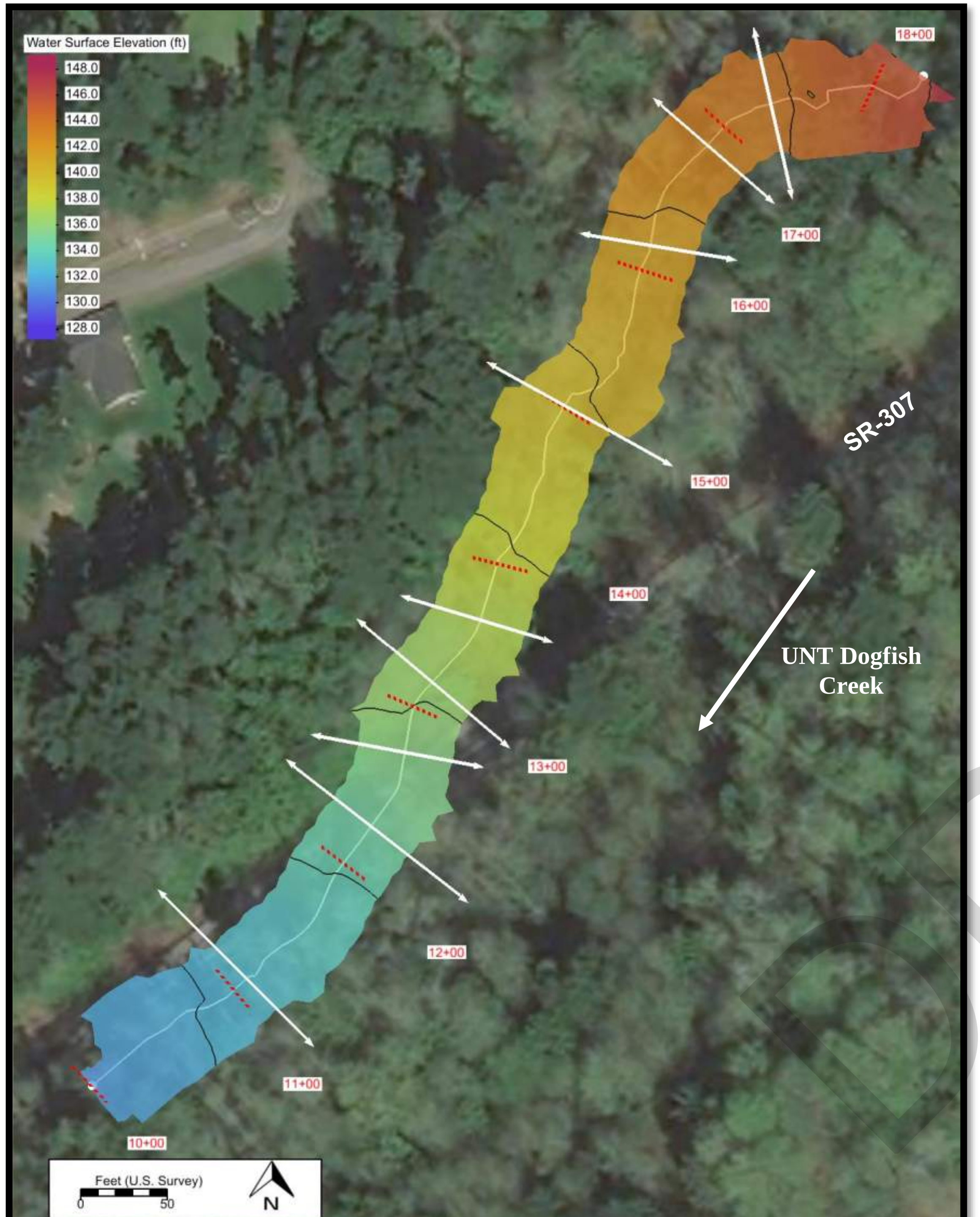
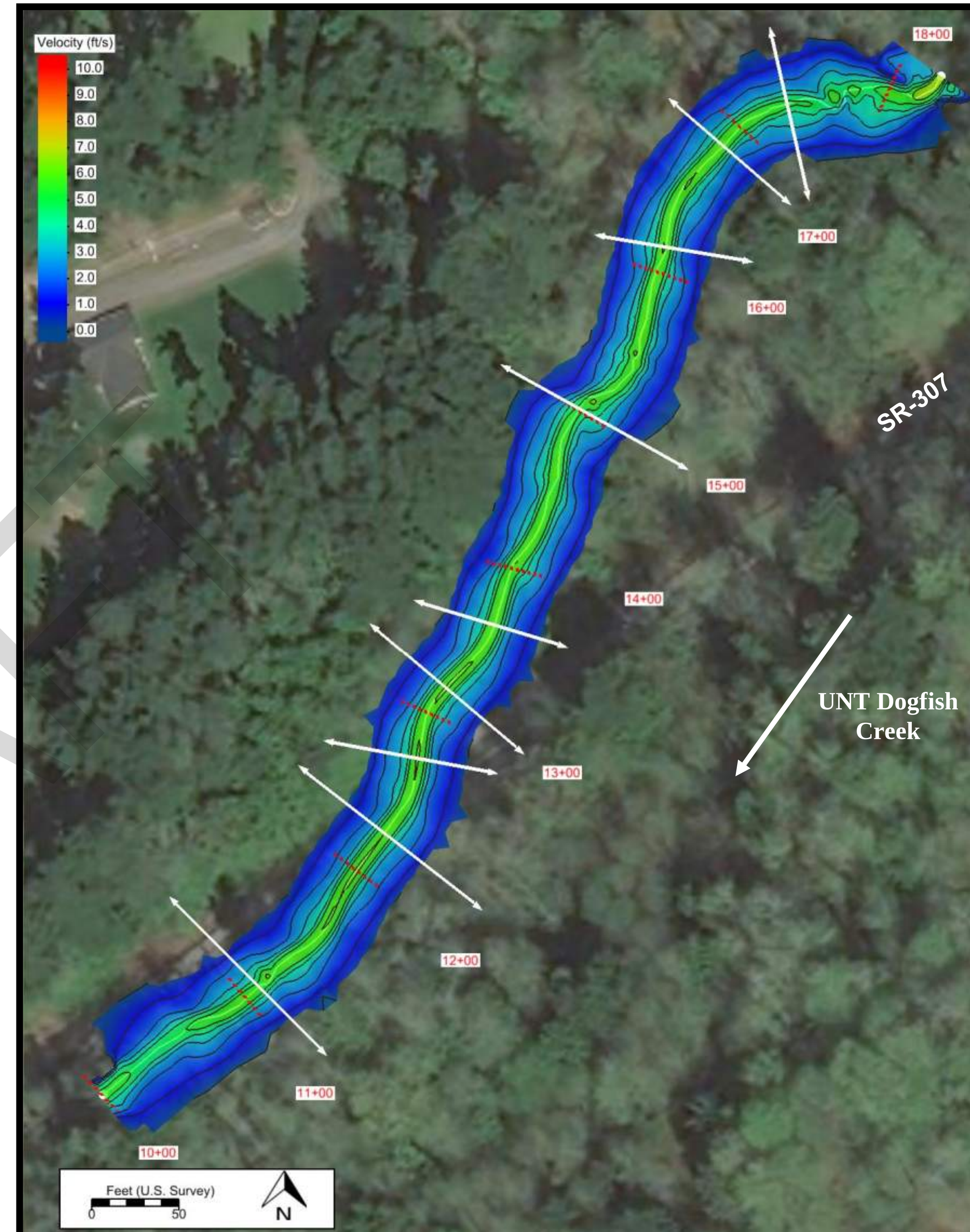
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022



Water Surface Elevation (FT NAVD88)



Velocity (FT/S)

Notes:

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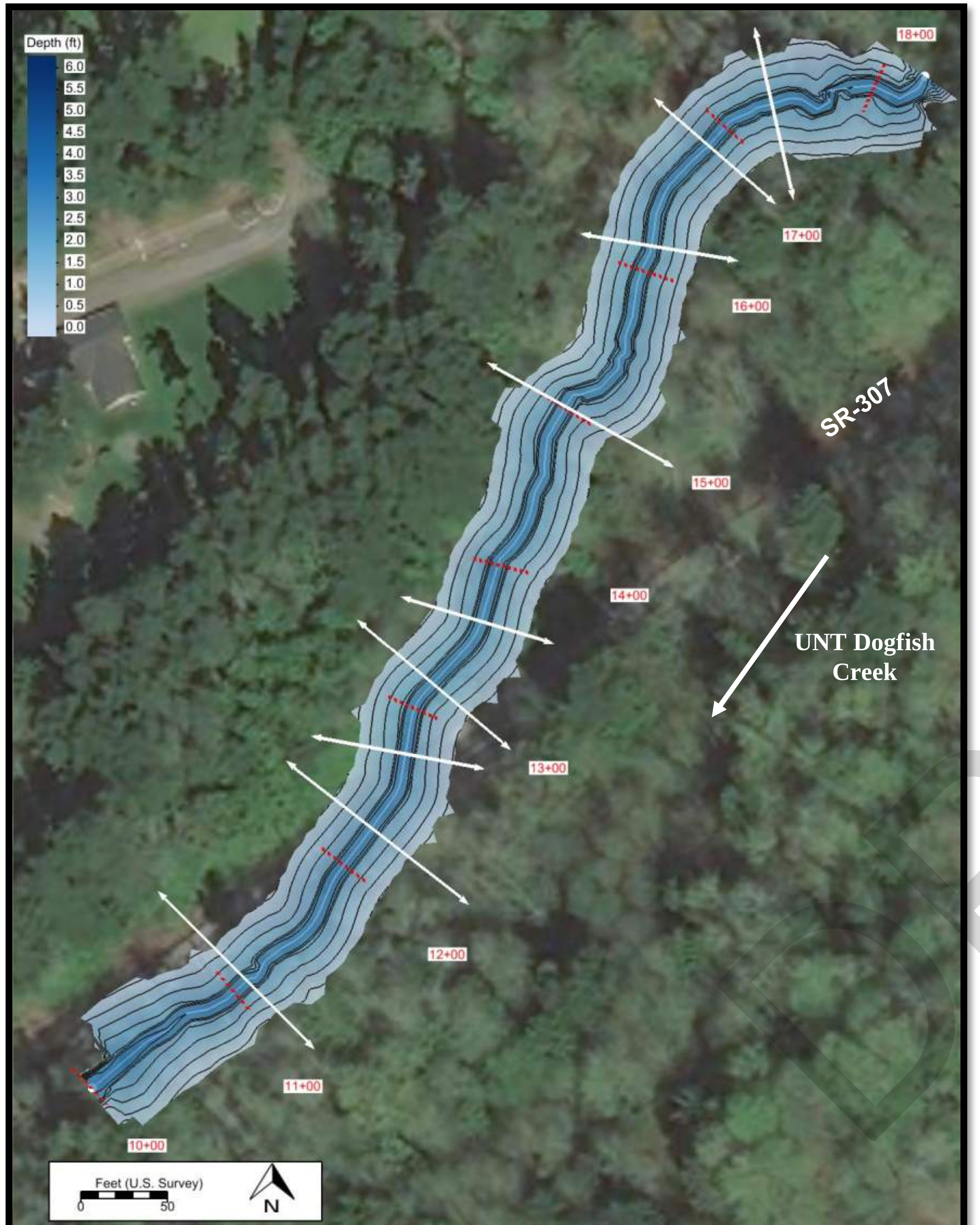
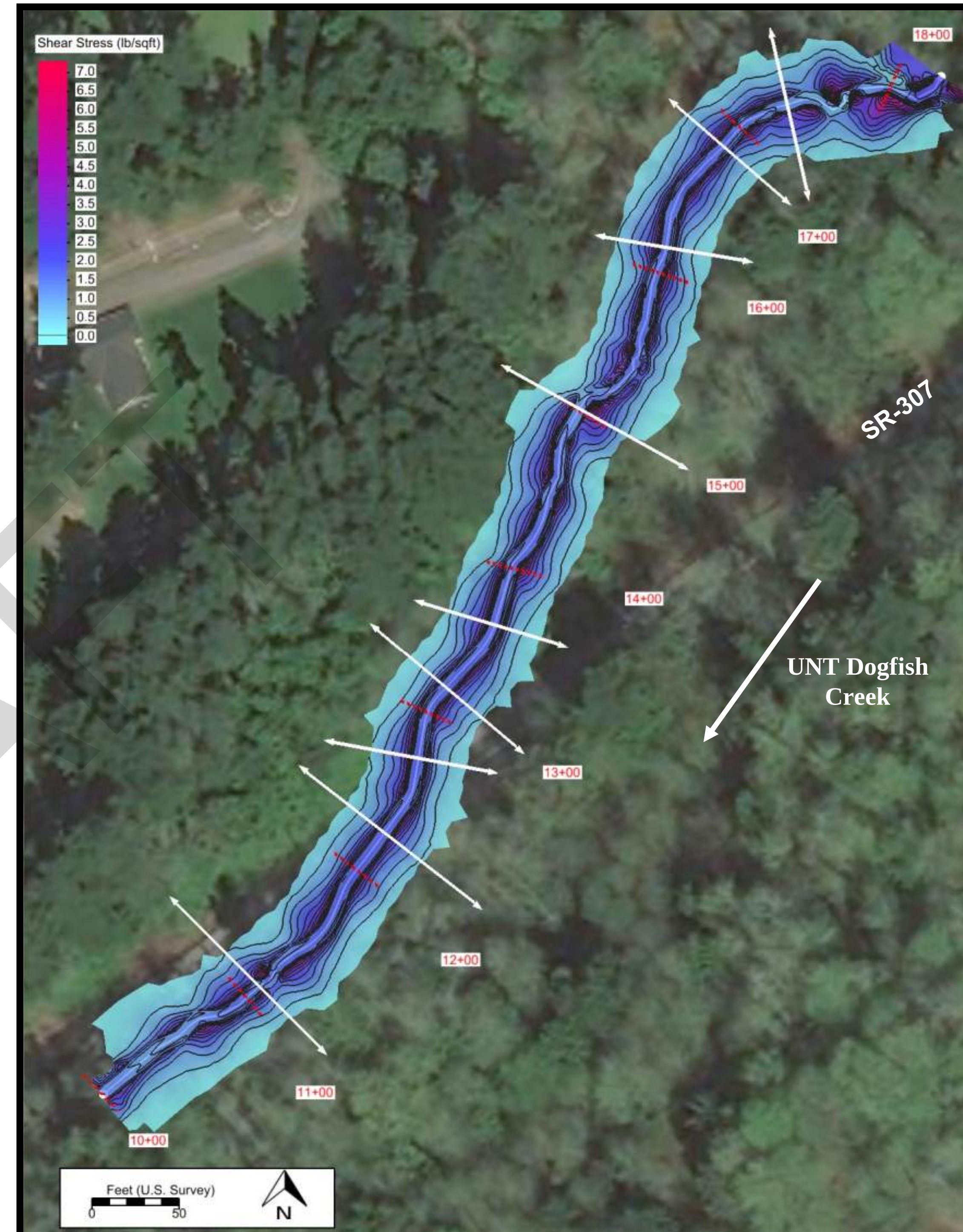
Natural Conditions Plan Views 500-year Event (234.1 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-24

00180-406-01 Date Exported: 09-21-22



Depth (FT)



Shear Stress (LB/SF)

Natural Conditions Plan Views
500-year Event (234.1 cfs)

UNT Dogfish Creek
Kitsap County

WSDOT GeoEngineers

Figure H-25

Notes:
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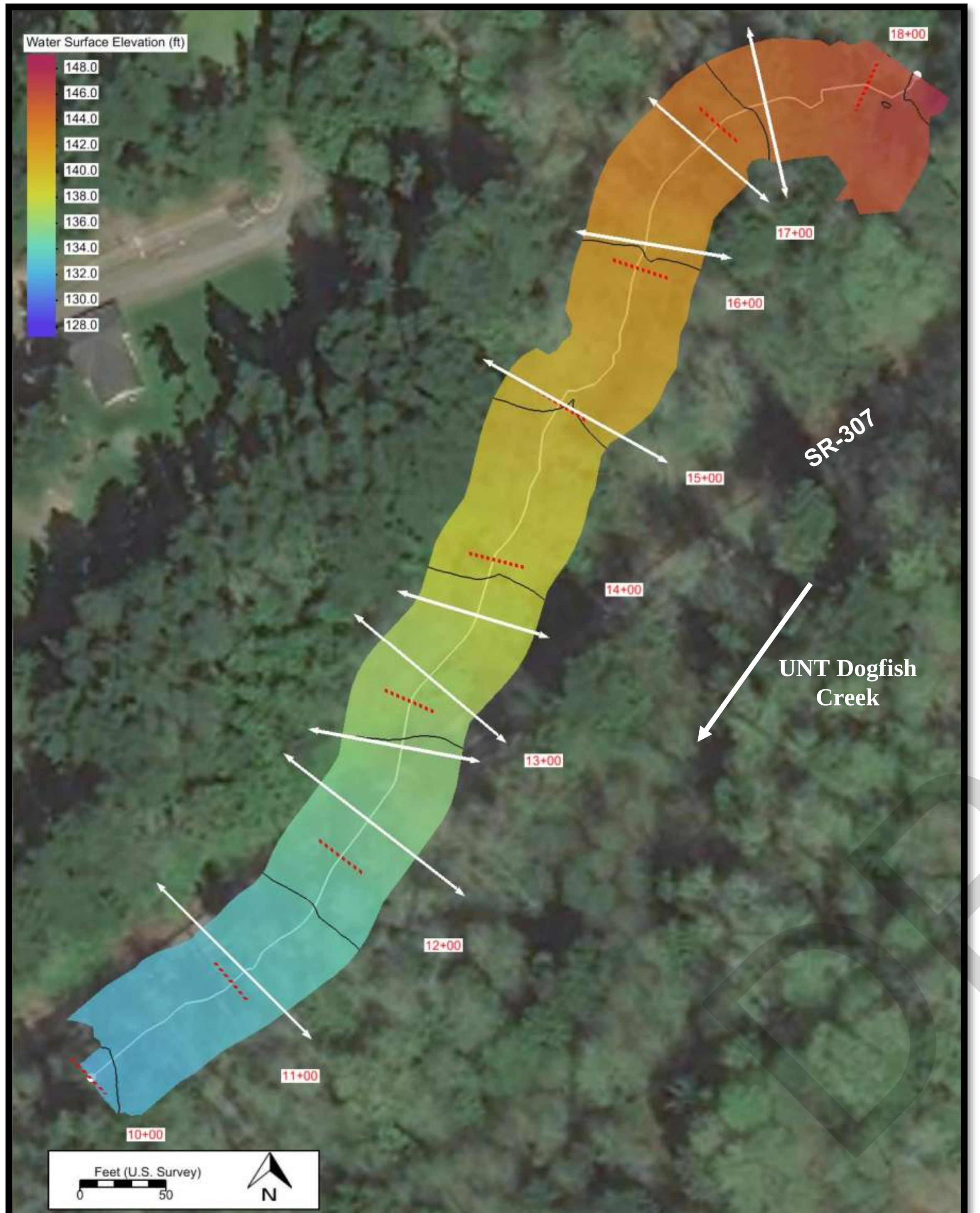
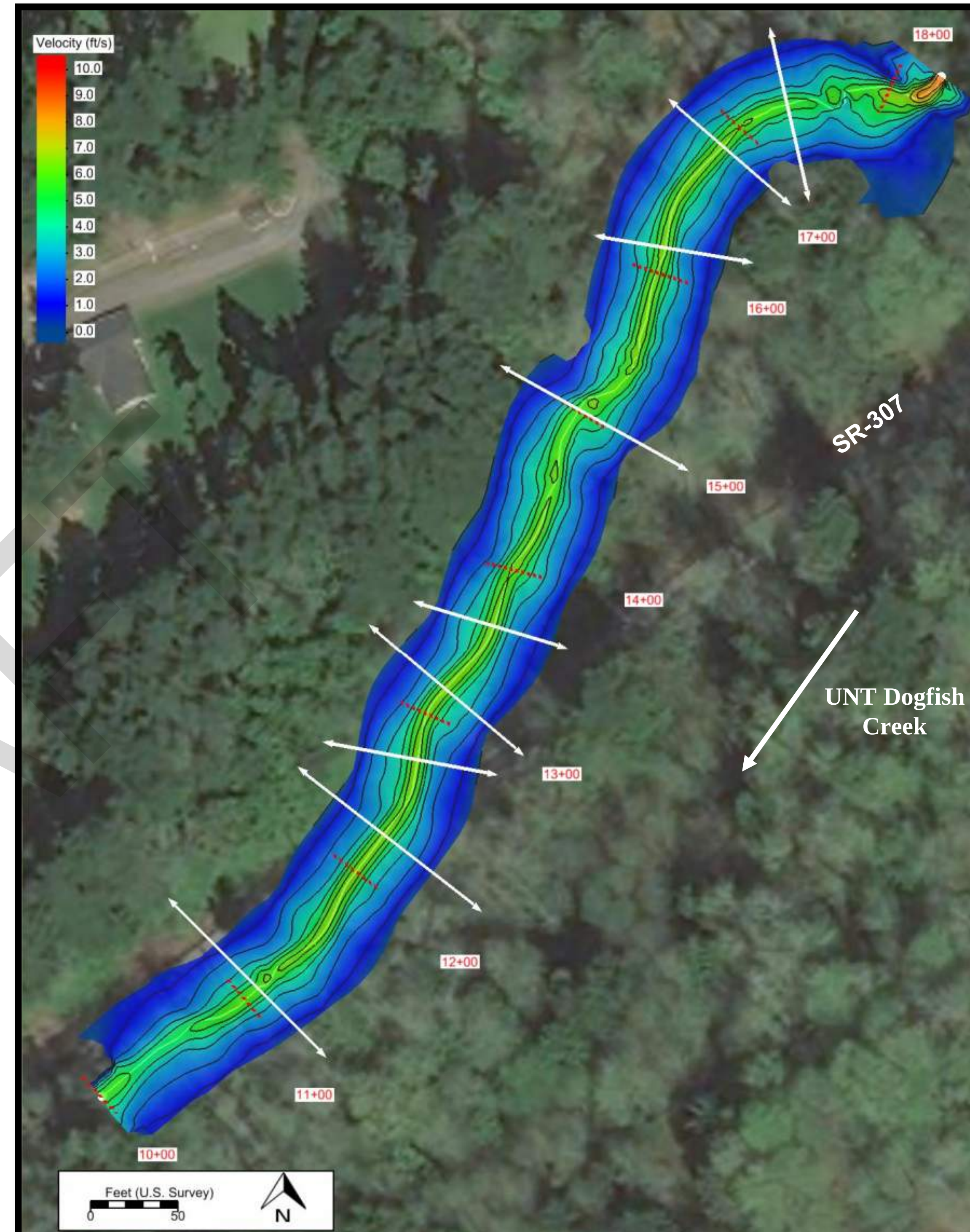
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

00180-406-01 Date Exported: 09-21-22



Water Surface Elevation (FT NAVD88)



Velocity (FT/S)

Natural Conditions Plan Views 2080 100-year Event (353.4 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-26

Notes:

1. The locations of all features shown are approximate.
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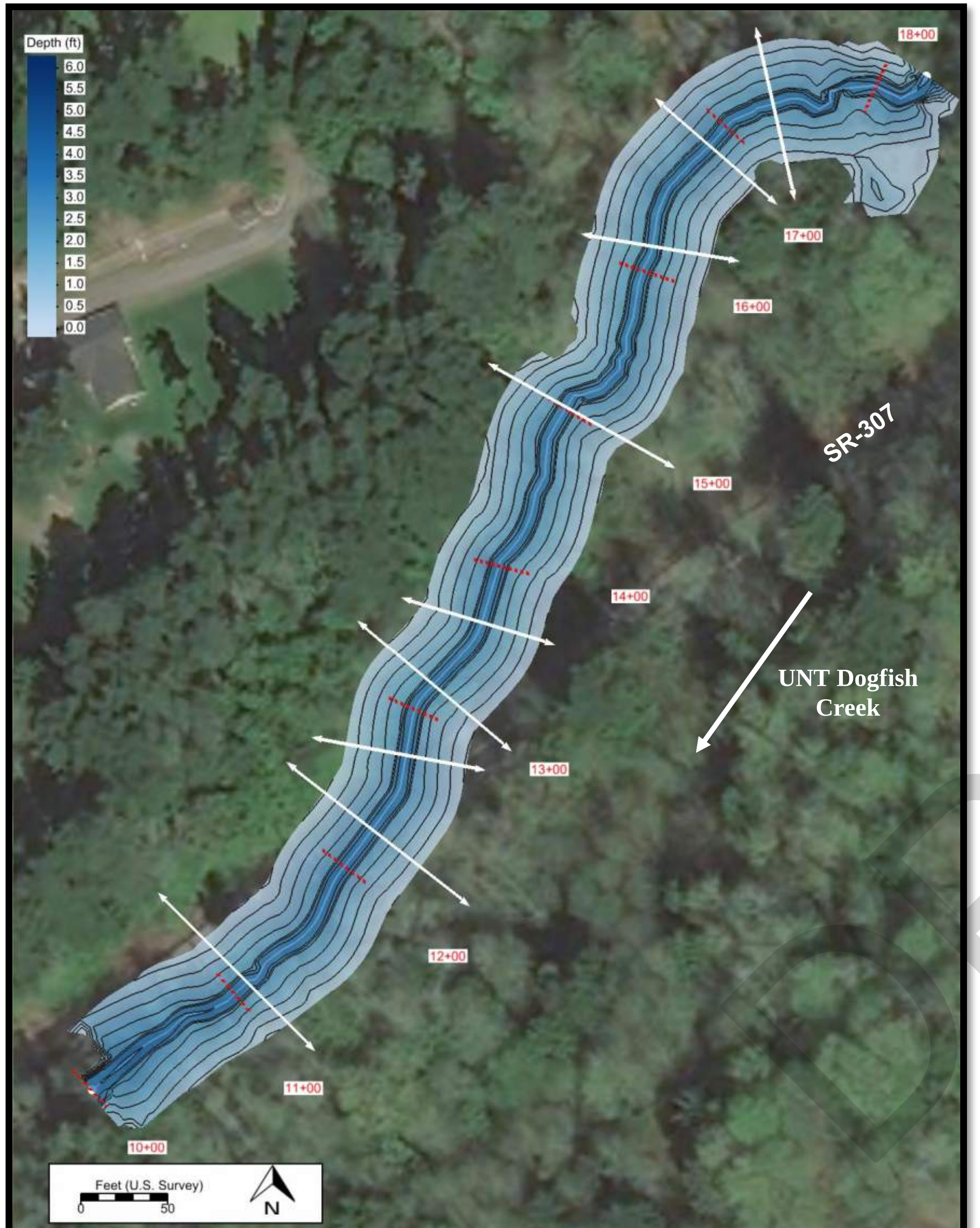
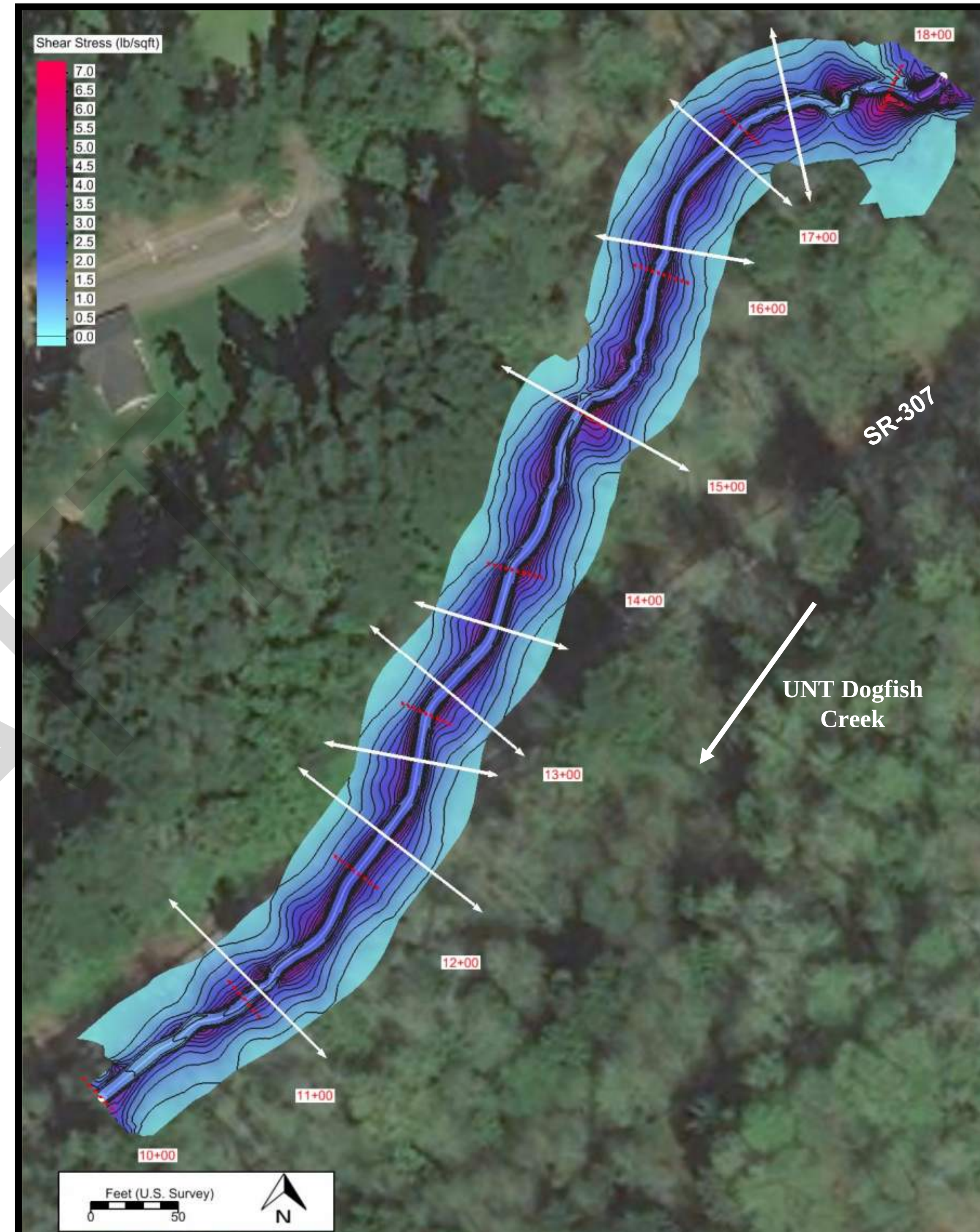
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

00180-406-01 Date Exported: 09-21-22



Depth (FT)



Shear Stress (LB/SF)

Notes:
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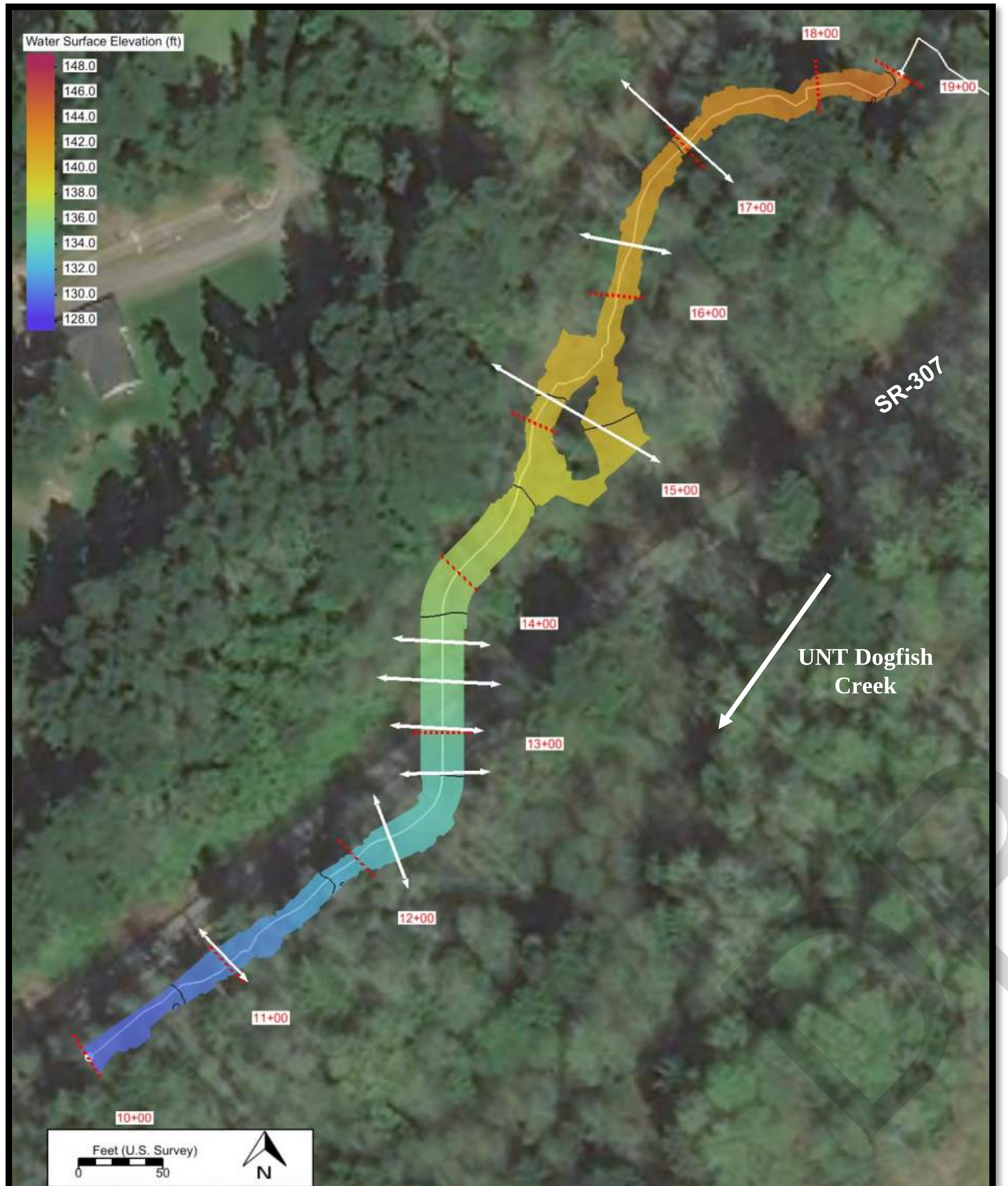
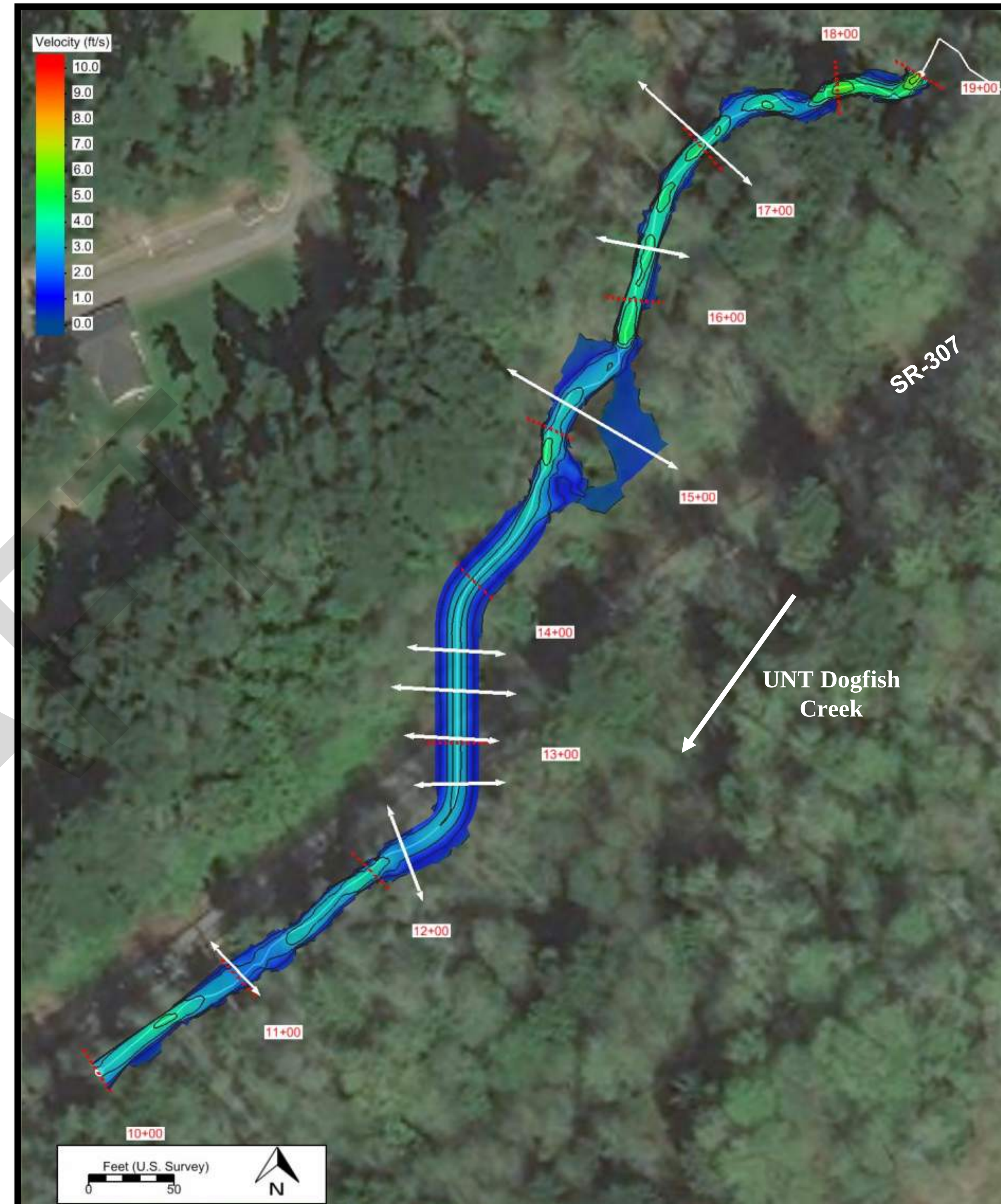
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Natural Conditions Plan Views 2080 100-year Event (353.4 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-27

00180-406-01 Date Exported: 09-21-22



Water Surface Elevation (FT NAVD88)



Velocity (FT/S)

Notes:

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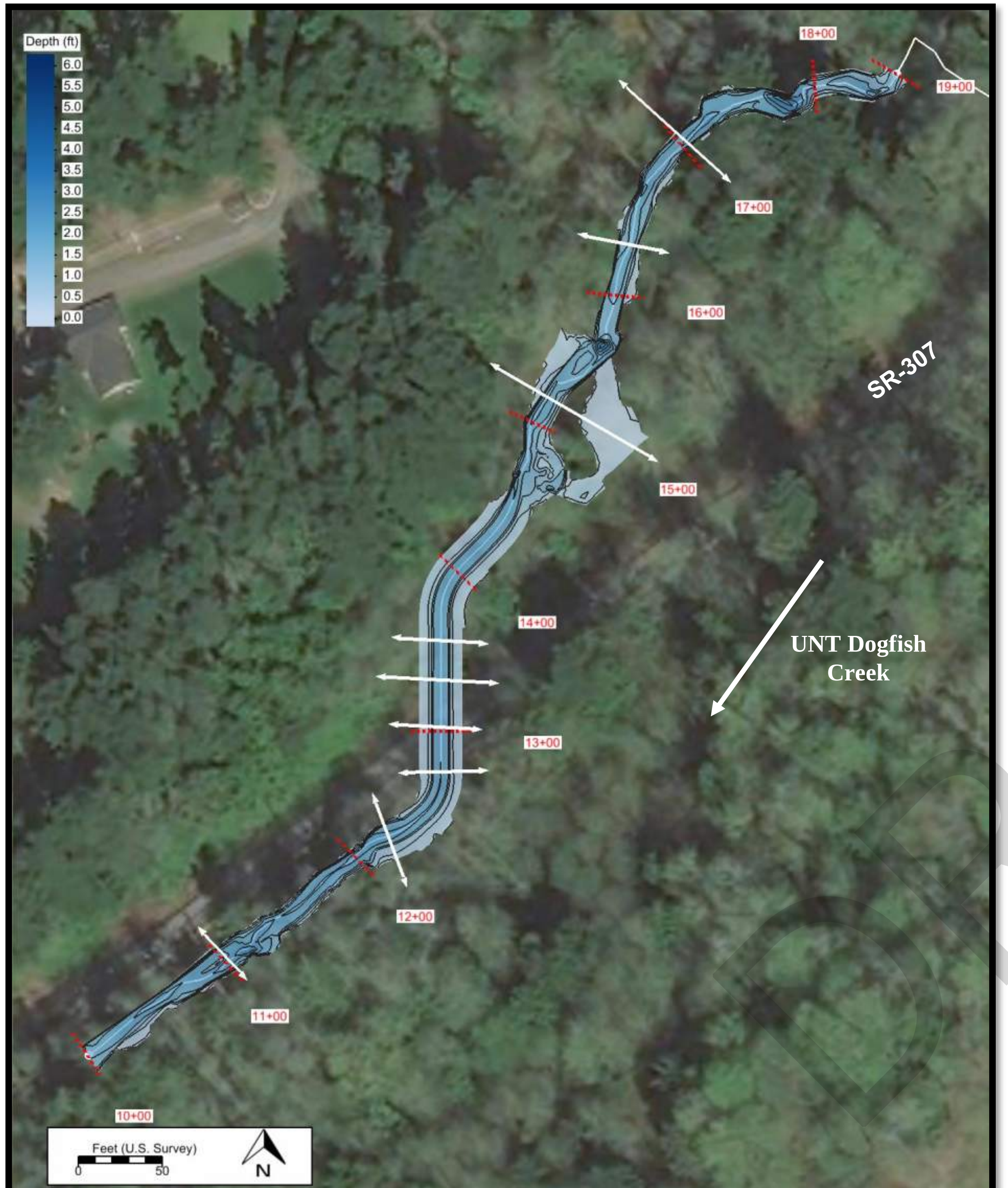
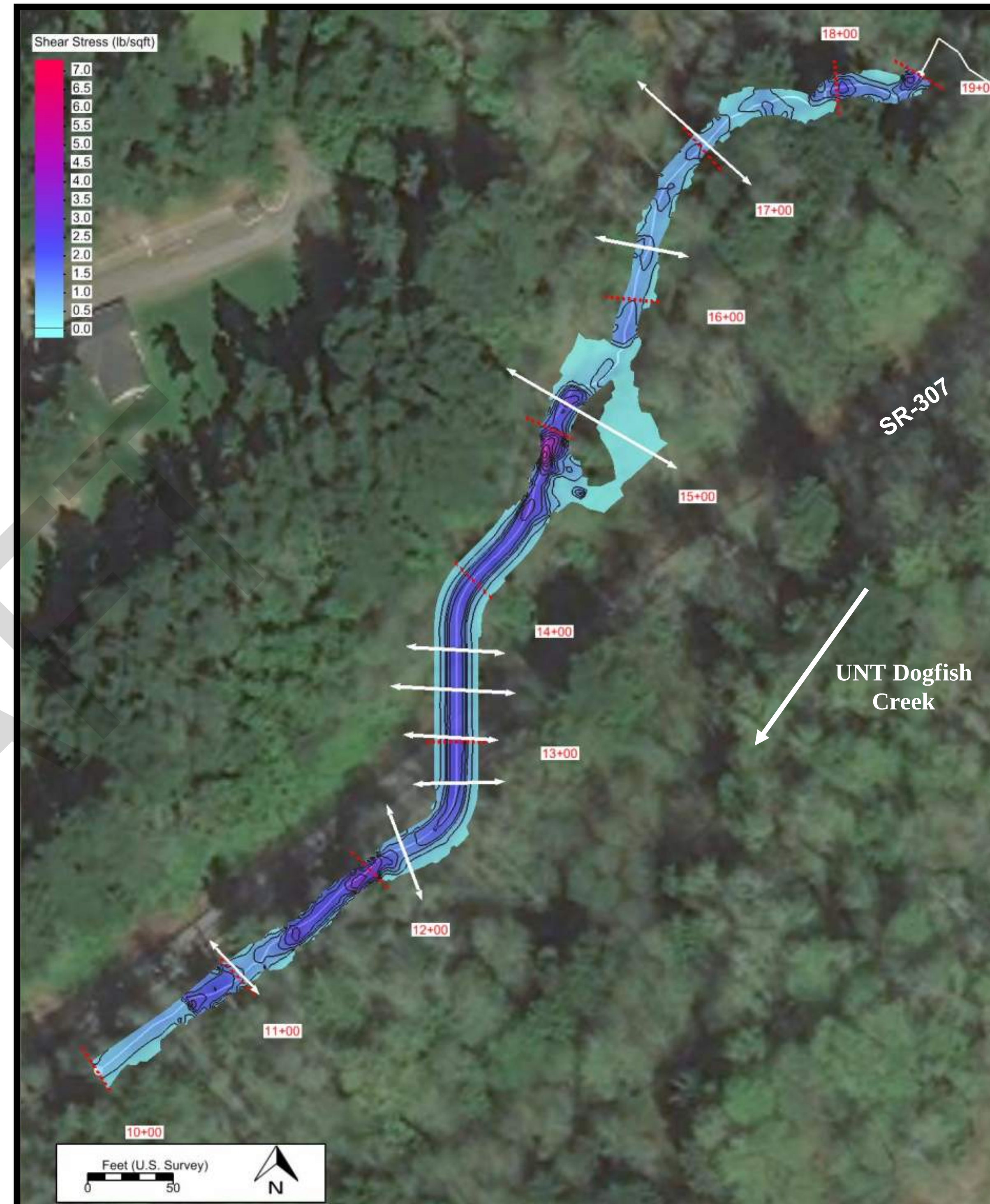
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Proposed Conditions Plan Views 2-year Event (61.5 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-28



Depth (FT)



Shear Stress (LB/SF)

Notes:

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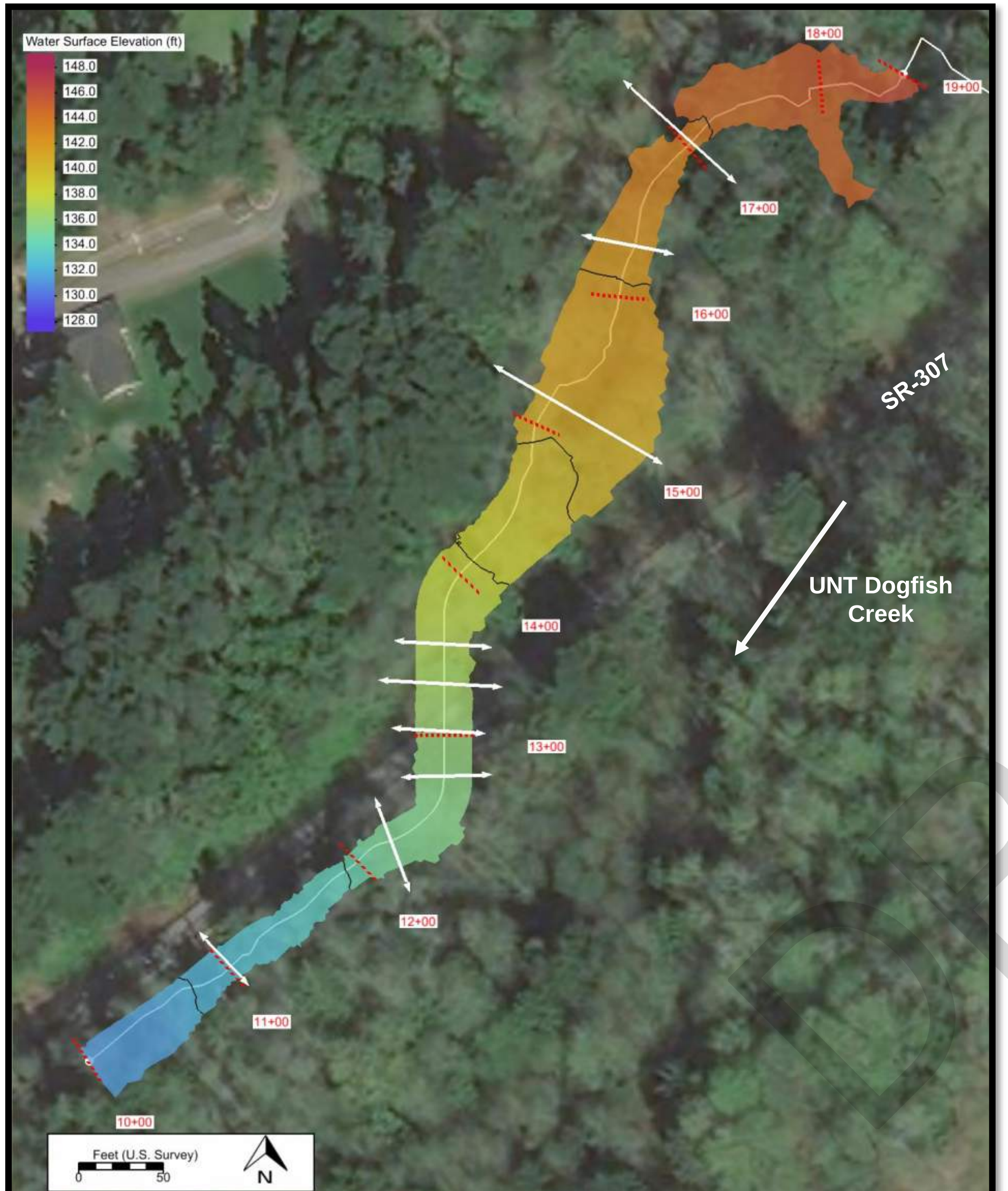
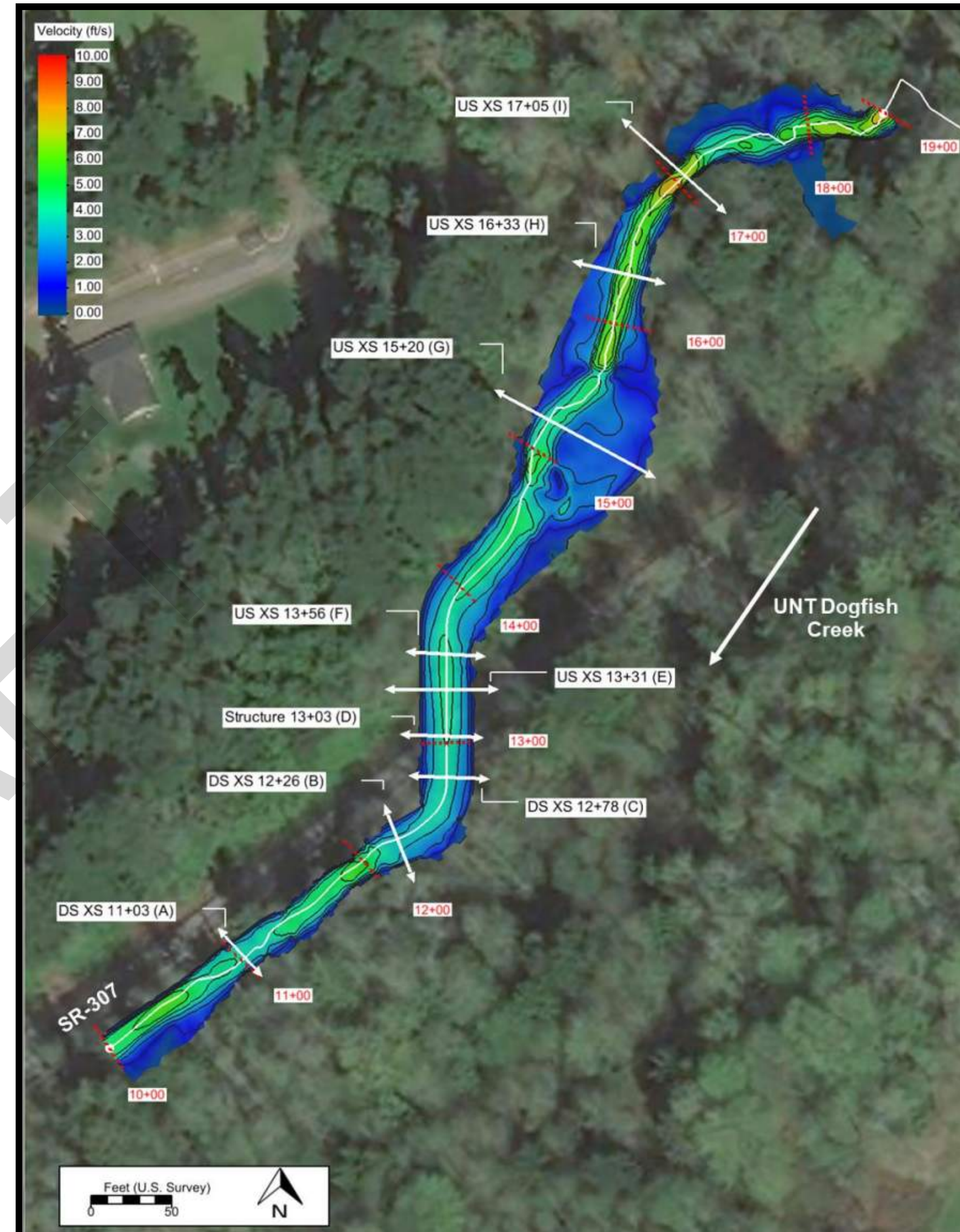
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Proposed Conditions Plan Views 2-year Event (61.5 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-29

00180-406-01 Date Exported: 09-21-22



Water Surface Elevation (FT NAVD88)



Velocity (FT/S)

Proposed Conditions Plan Views 100-year Event (218.8 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-30

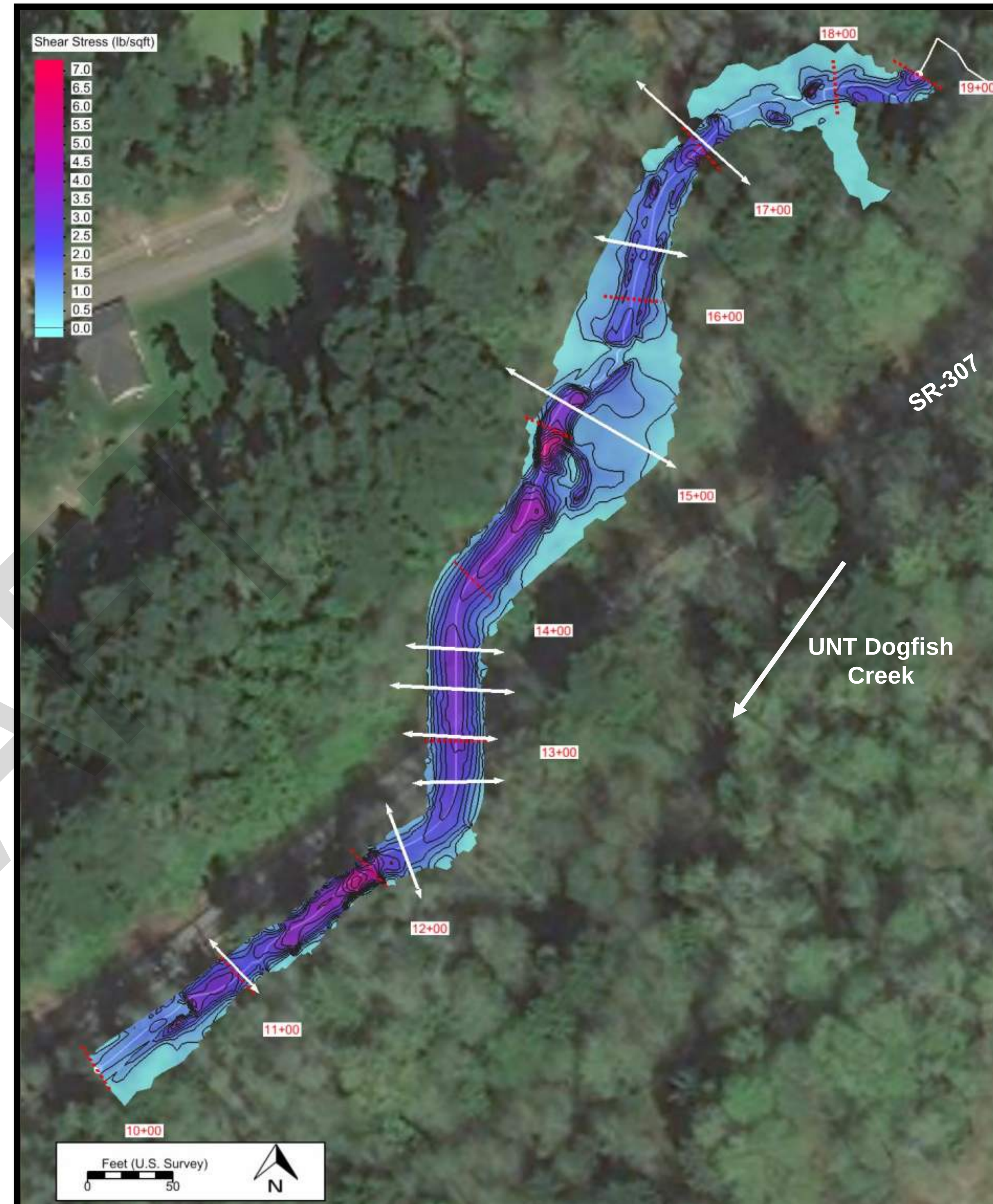
Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

00180-406-01 Date Exported: 09-21-22

Depth (FT)



Shear Stress (LB/SF)

Notes:

1. The locations of all features shown are approximate.
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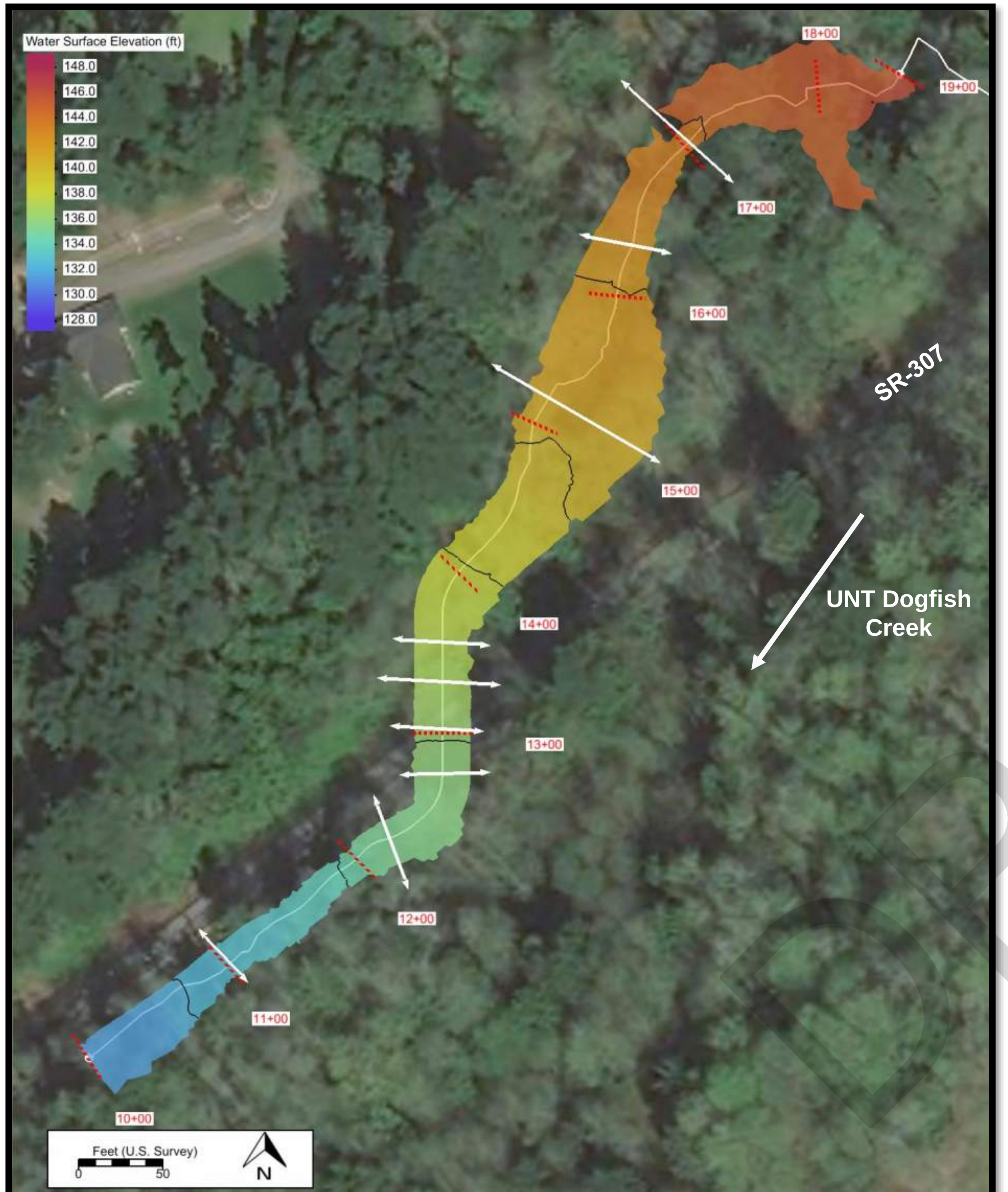
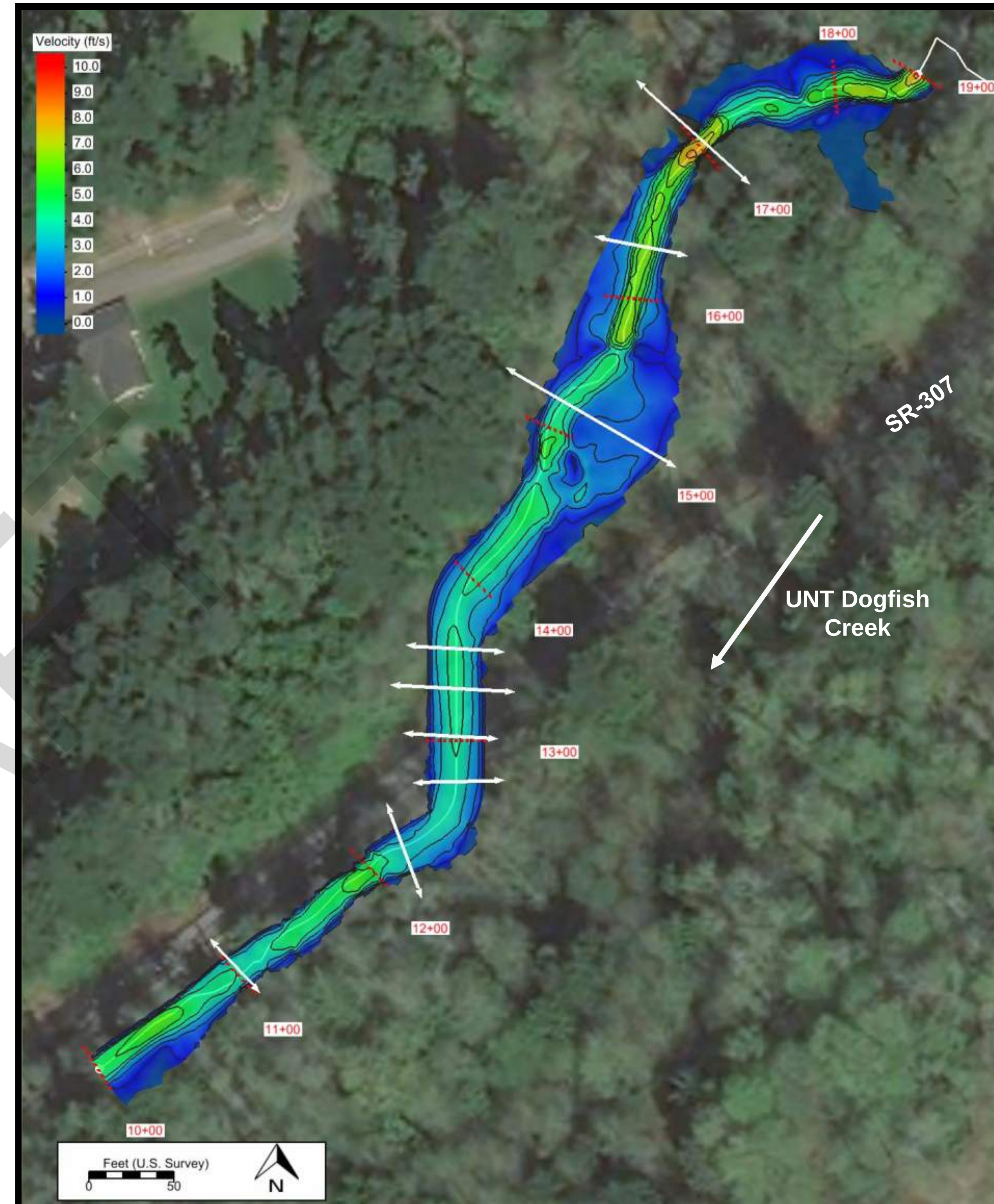
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Proposed Conditions Plan Views 100-year Event (218.8 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	**Figure H-31**

00180-406-01 Date Exported: 09-21-22



Water Surface Elevation (FT NAVD88)



Velocity (FT/S)

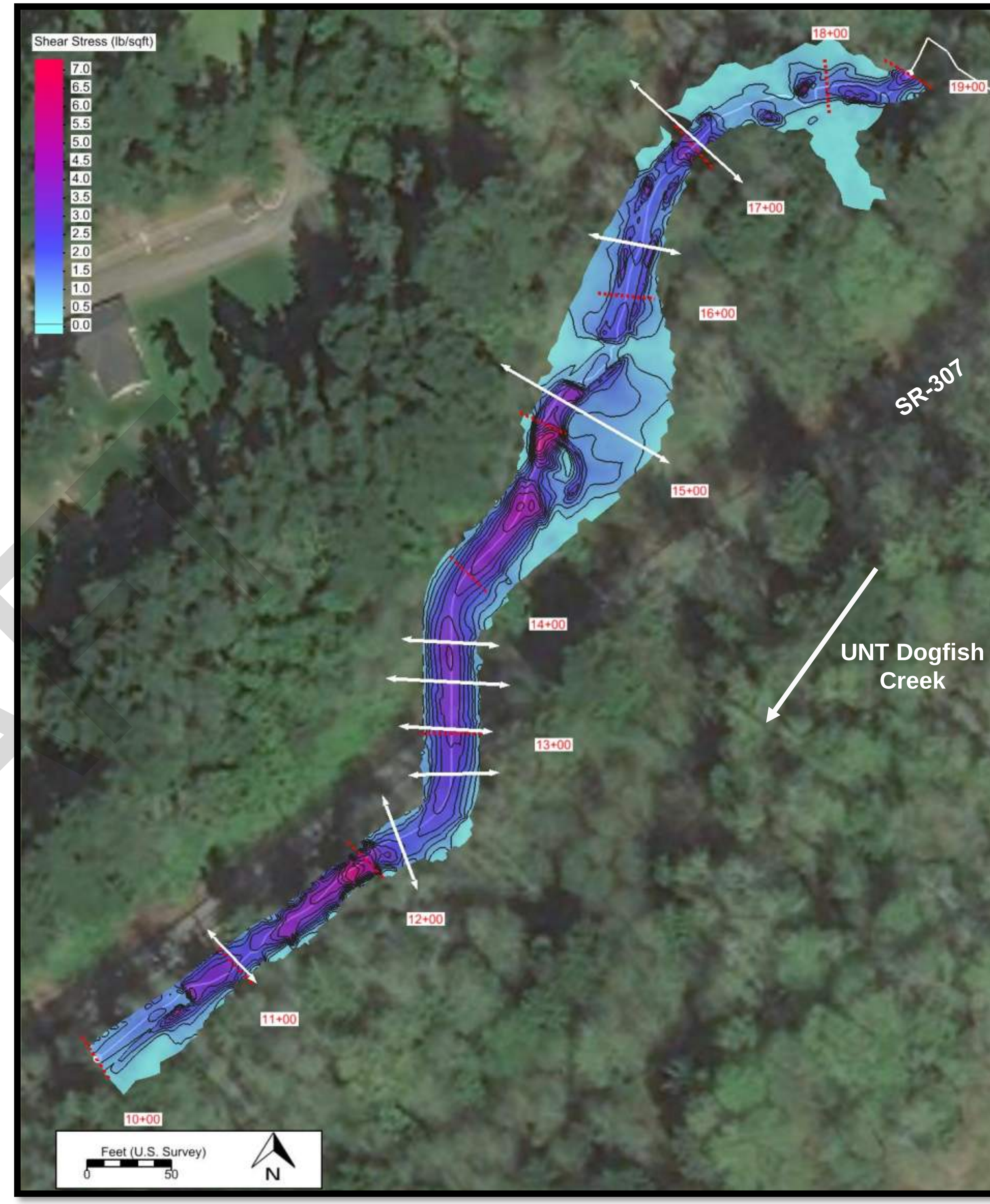
Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Proposed Conditions Plan Views 500-year Event (234.1 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-32

00180-406-01 Date Exported: 09-21-22

Depth (FT)



Shear Stress (LB/SF)

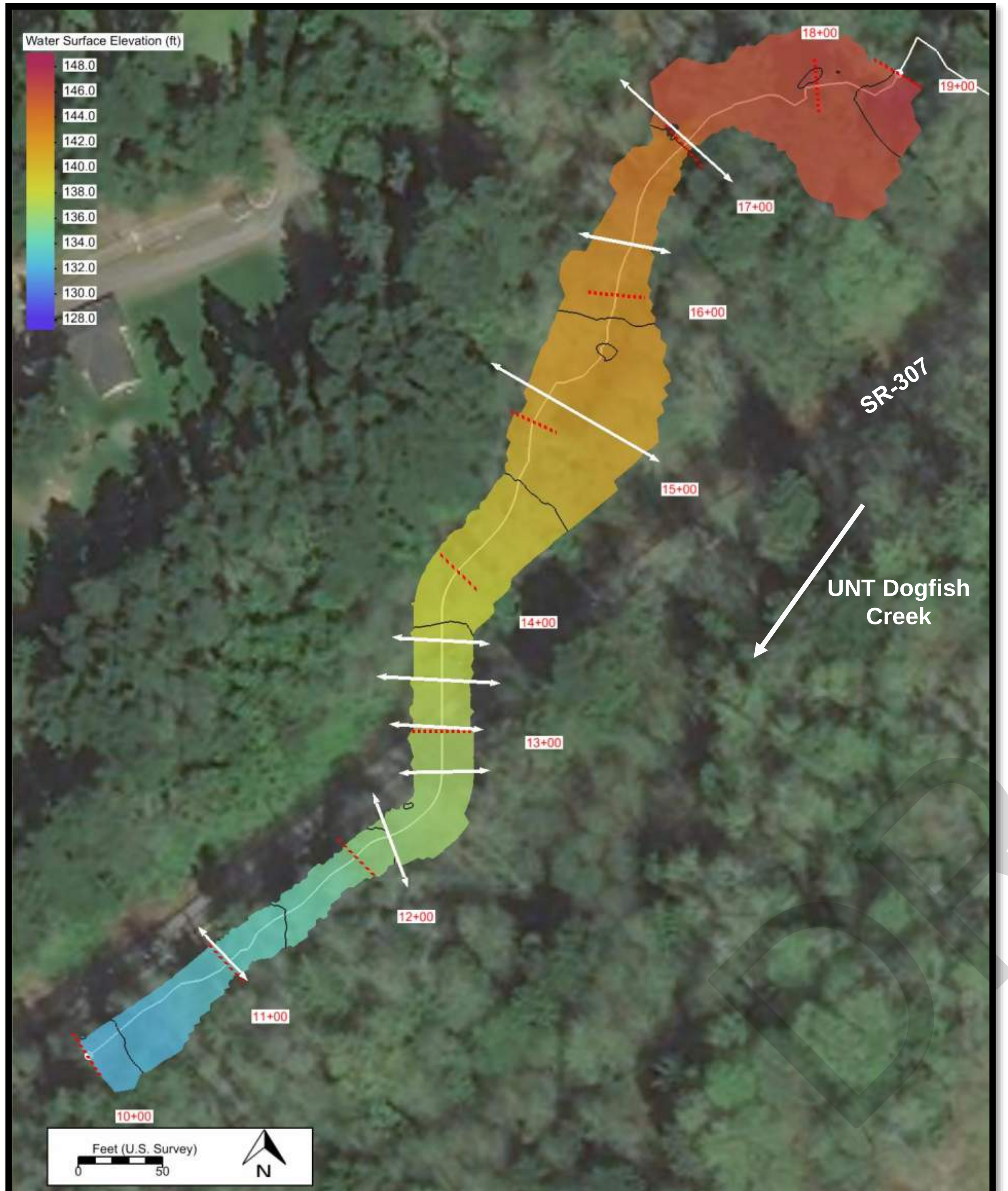
Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

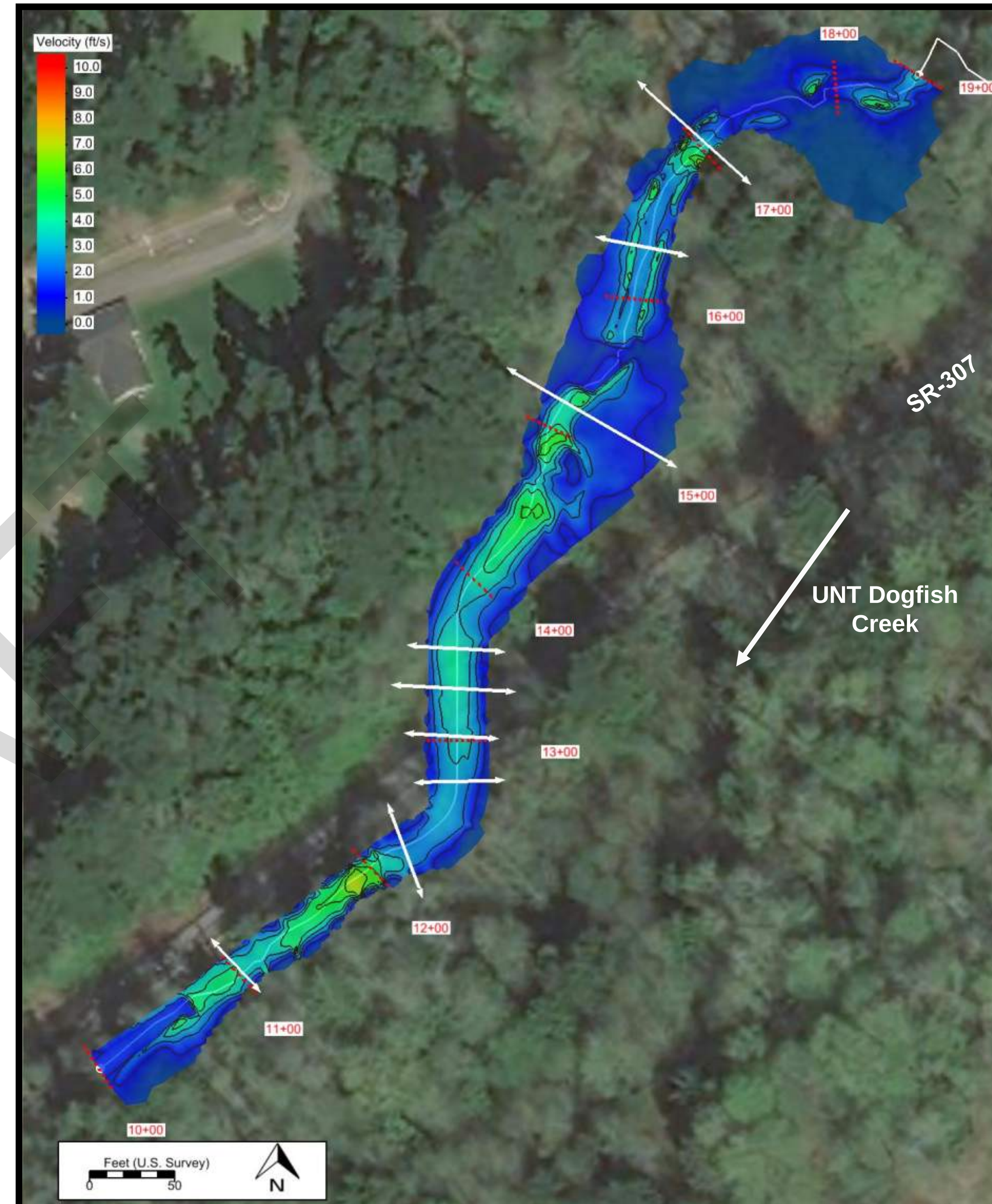
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Proposed Conditions Plan Views 500-year Event (234.1 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-33

00180-406-01 Date Exported: 09-21-22



Water Surface Elevation (FT NAVD88)



Velocity (FT/S)

Notes:

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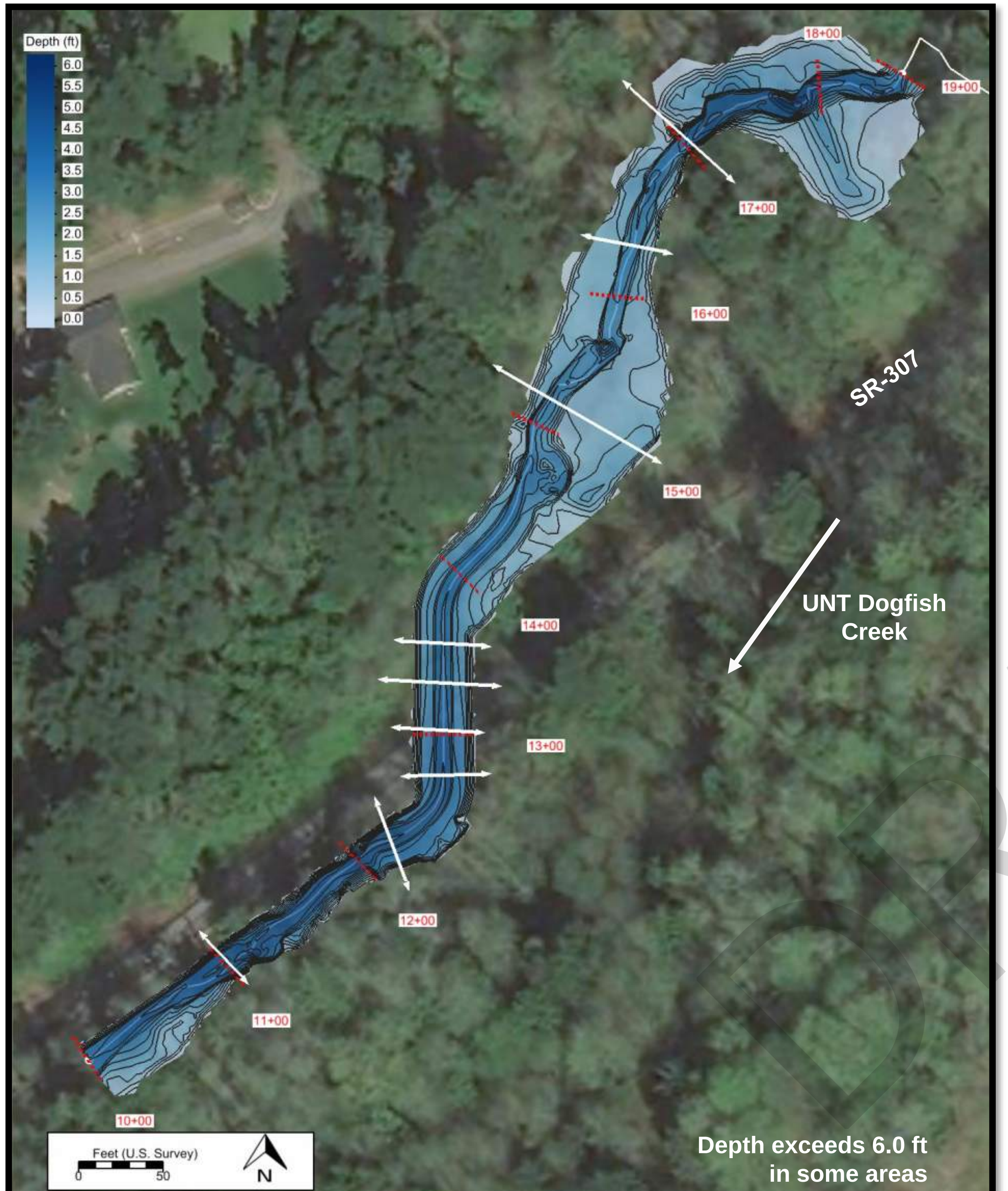
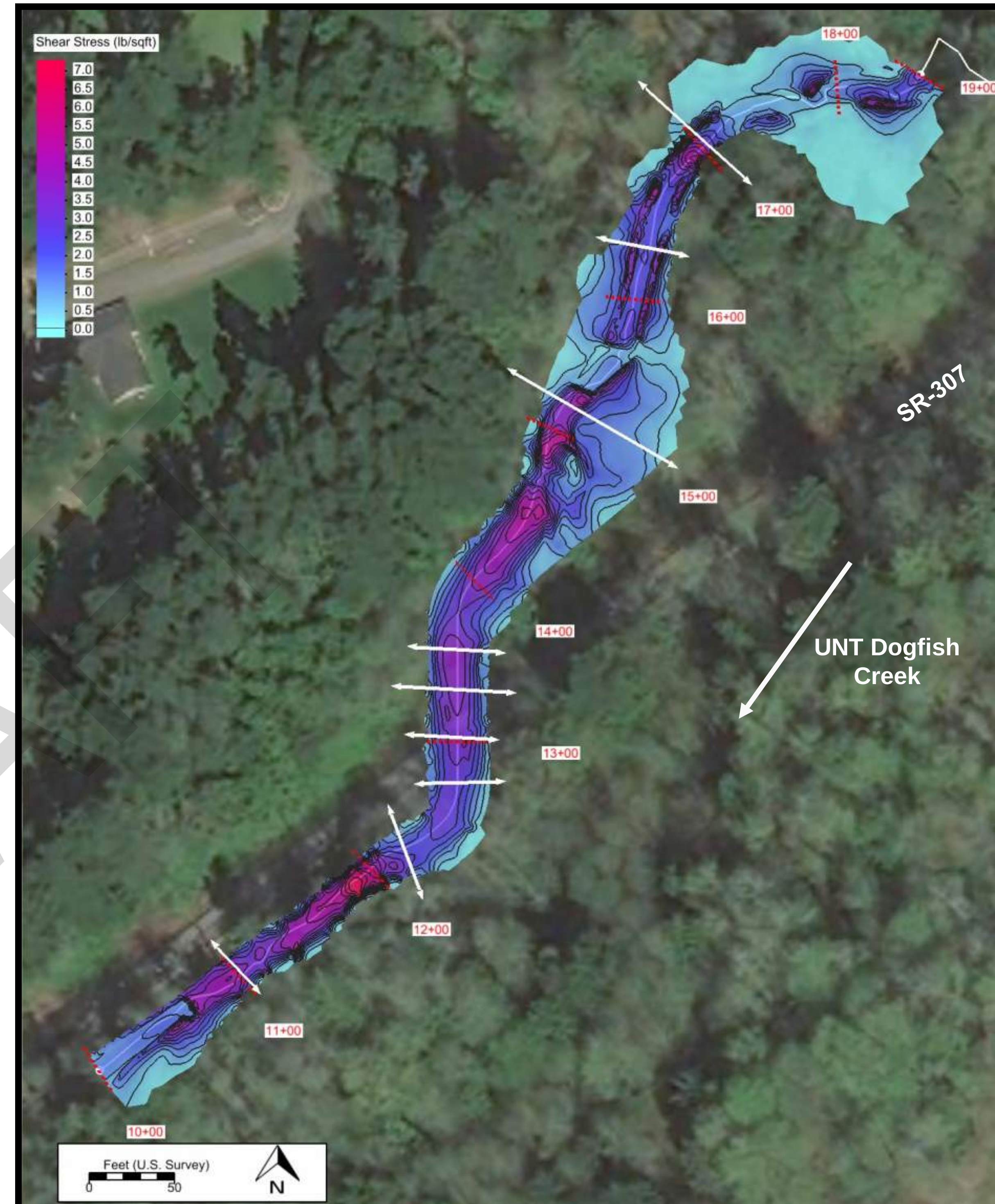
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

Proposed Conditions Plan Views 2080 100-year Event (353.4 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	Figure H-34

00180-406-01 Date Exported: 09-21-22



Depth (FT)



Shear Stress (LB/SF)

Notes:
1. The locations of all features shown are approximate.
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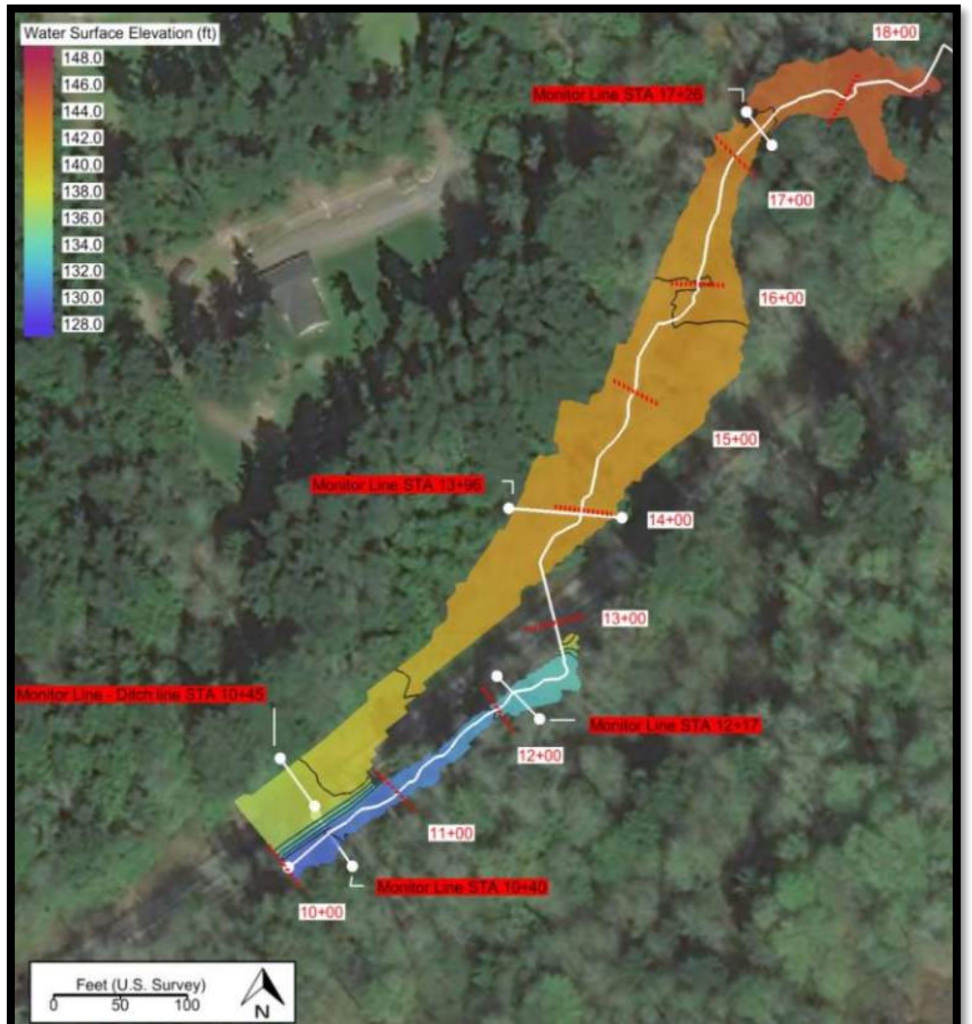
Data Source: SMS Version 13.1.21 and SRH-2D Version 3.3.0; Simulation Date: September 2022

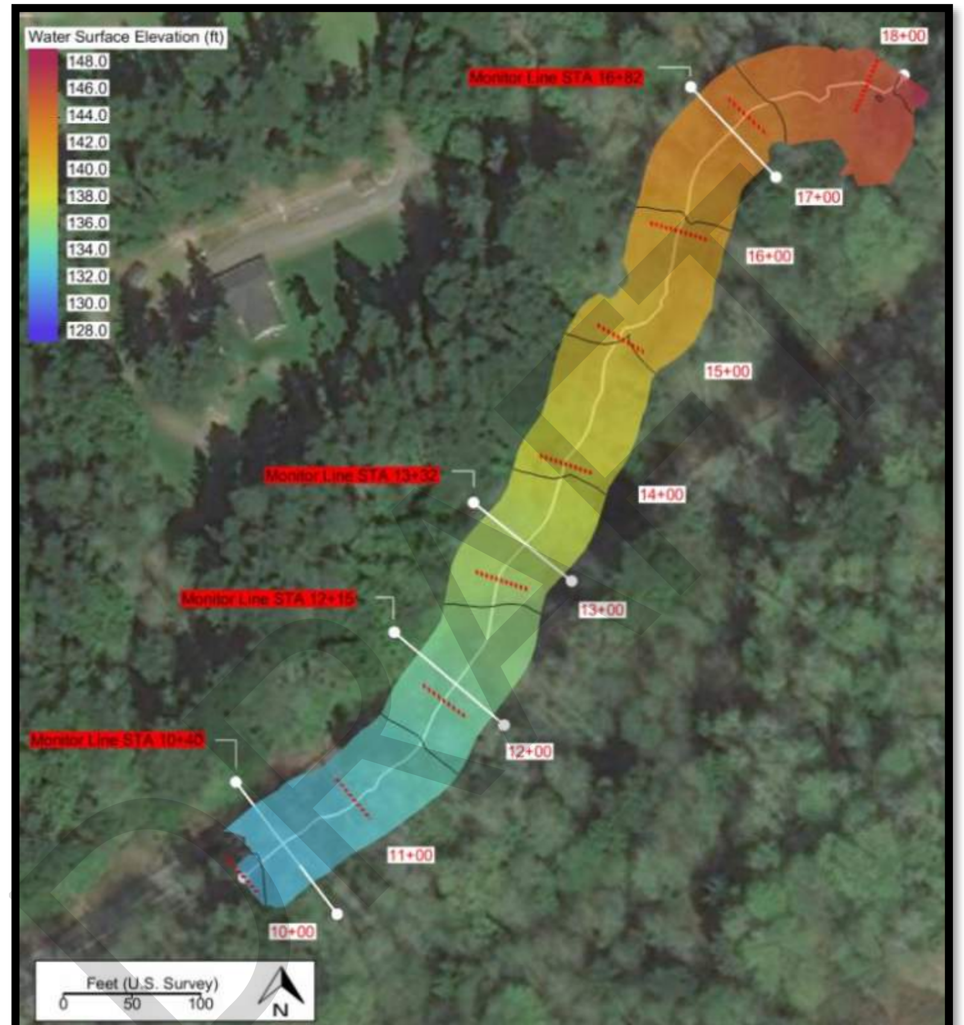
Proposed Conditions Plan Views 2080 100-year Event (353.4 cfs)	
UNT Dogfish Creek Kitsap County	
WSDOT GeoEngineers	**Figure H-35**

00180-406-01 Date Exported: 09-21-22

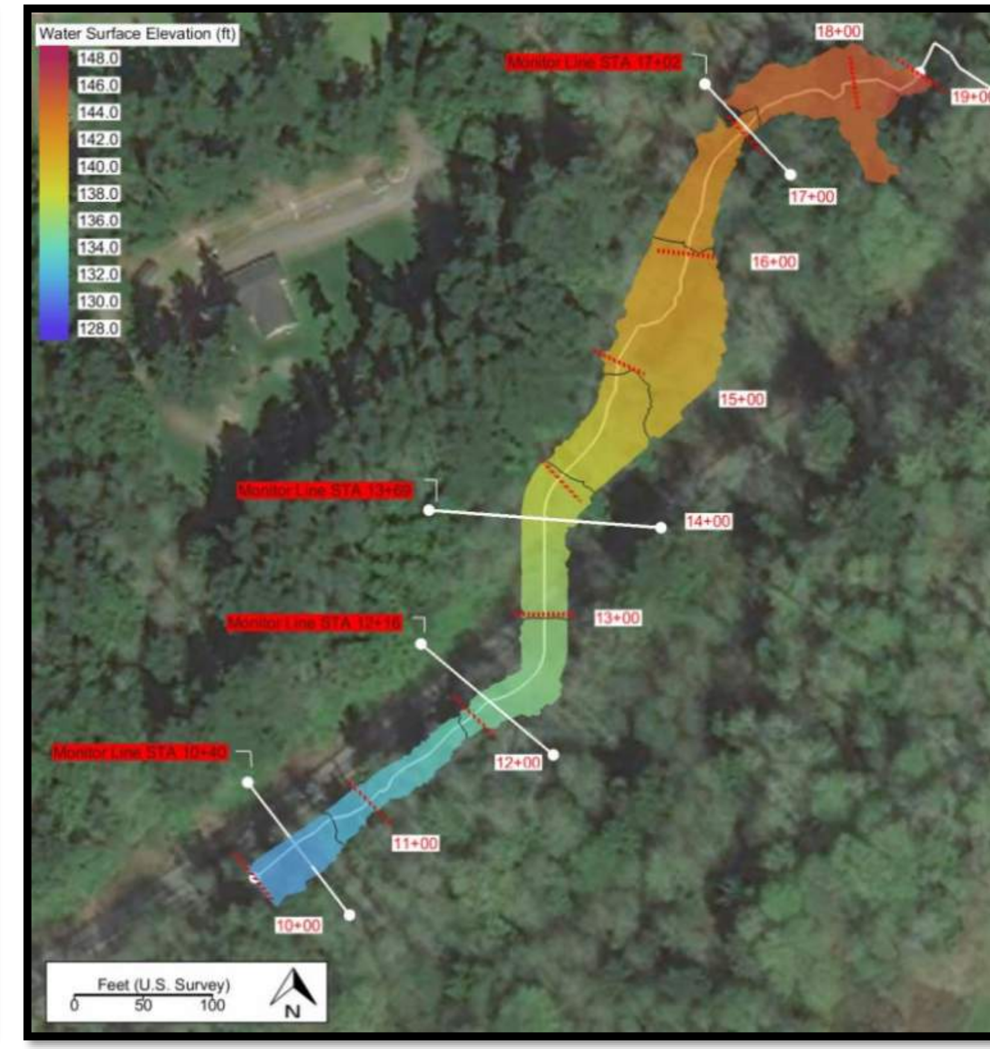
Appendix I: SRH-2D Model Stability and Continuity



Existing conditions monitoring line locations with 500-year WSEL results



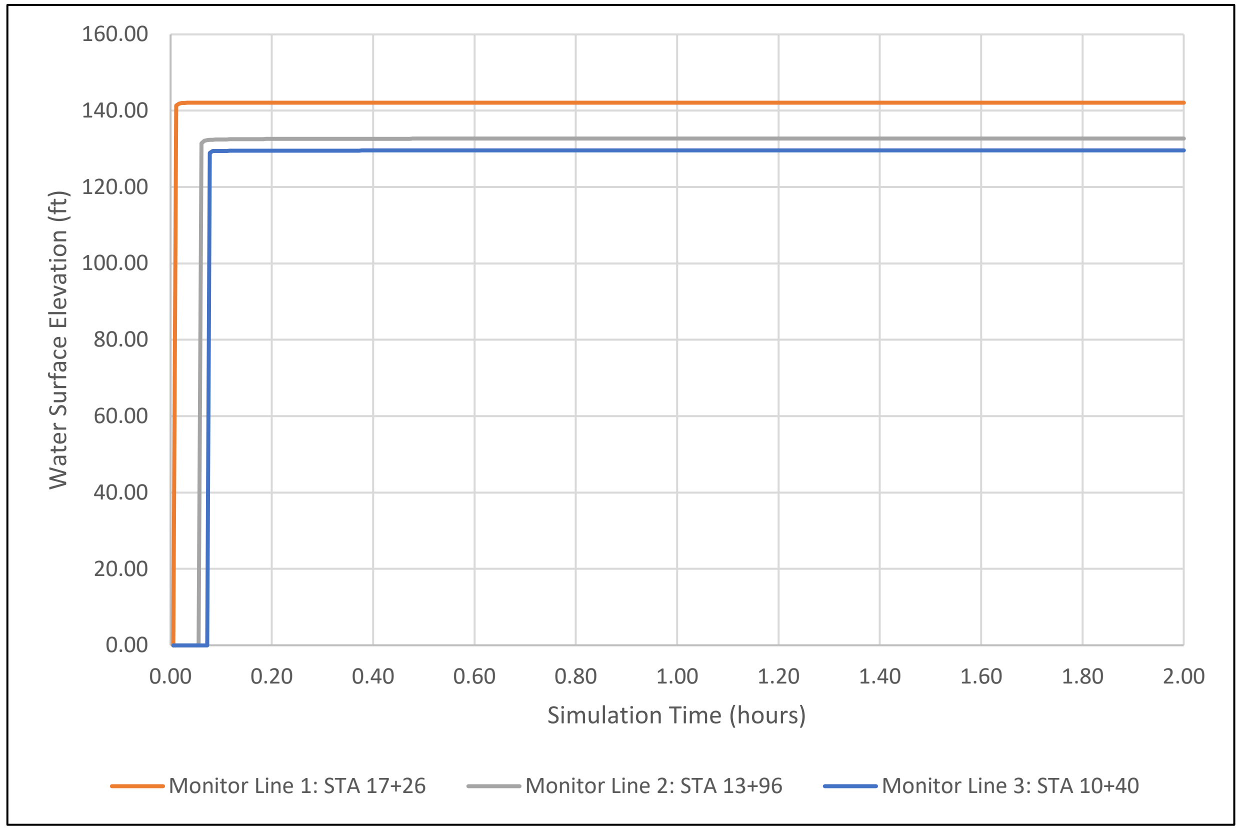
Natural conditions monitoring line locations with 500-year WSEL results



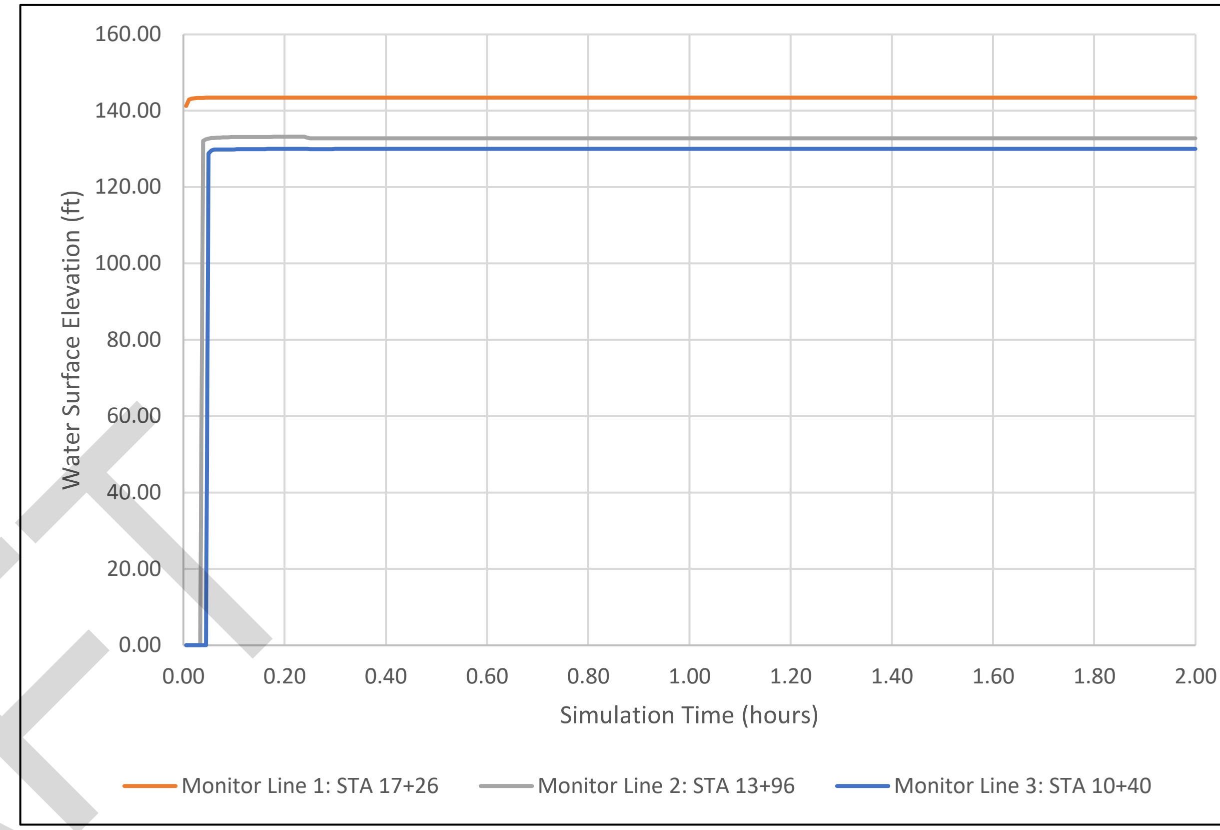
Proposed conditions monitoring line locations with 500-year WSEL results

Data Source: SMS version 13.1.21 and SRH-2D version 3.3.0

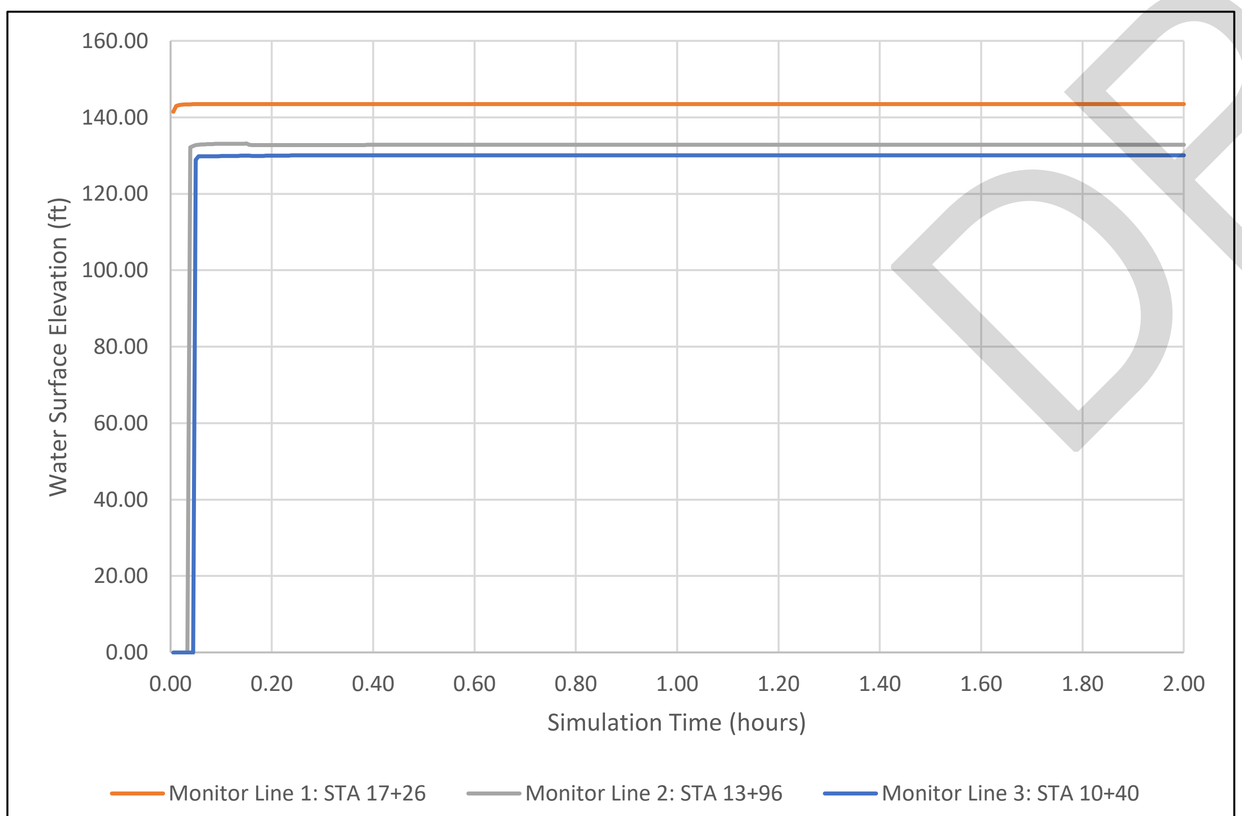
Appendix I: SRH-2D Model Stability and Continuity



Existing conditions 2-year event monitor line average WSEL results



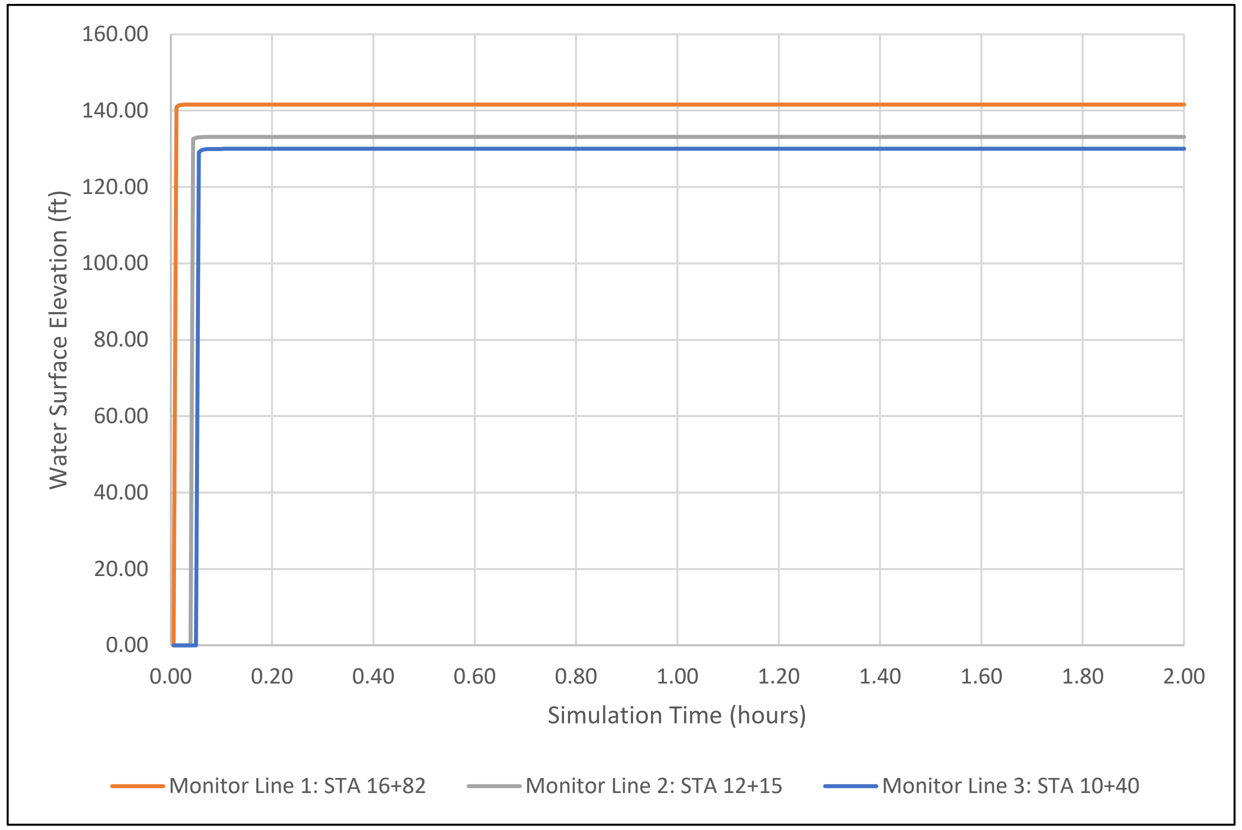
Existing conditions 100-year event monitor line average WSEL results



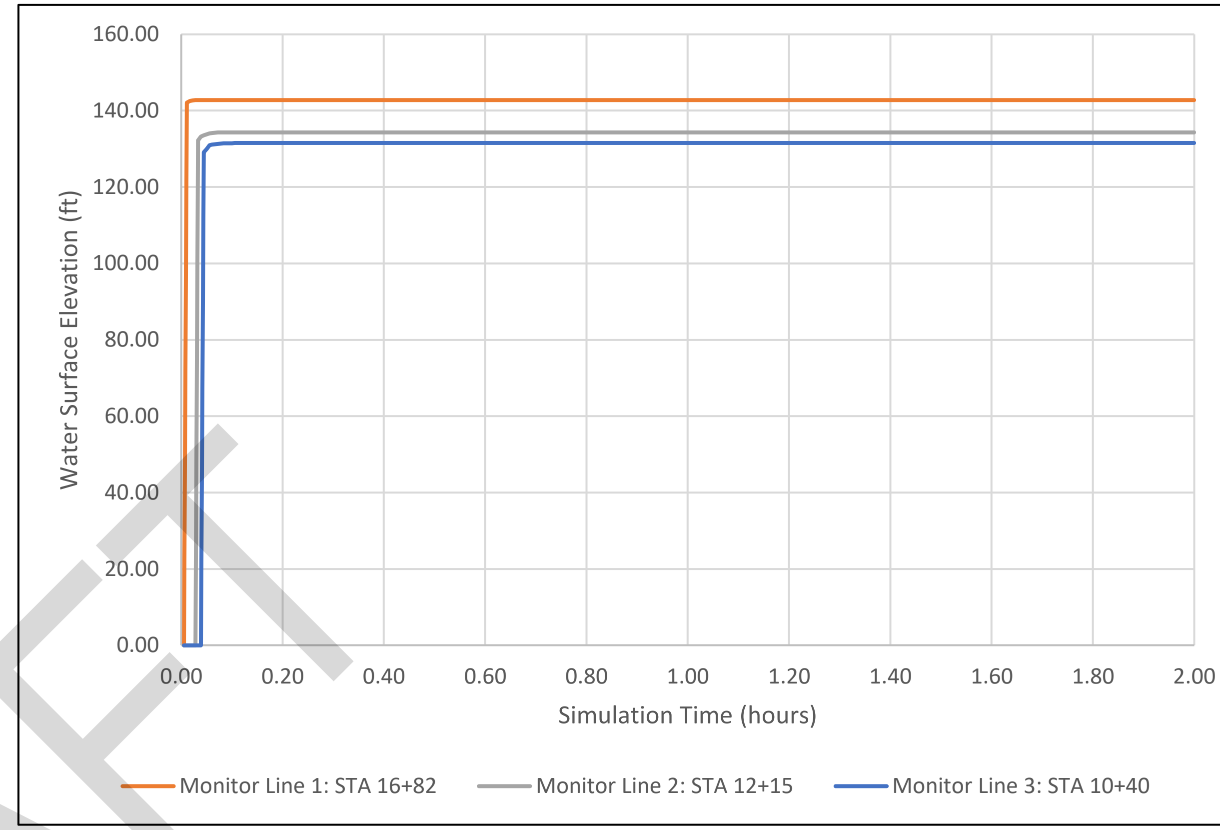
Existing conditions 500-year event monitor line average WSEL results

Data Source: SMS version 13.1.21 and SRH-2D version 3.3.0

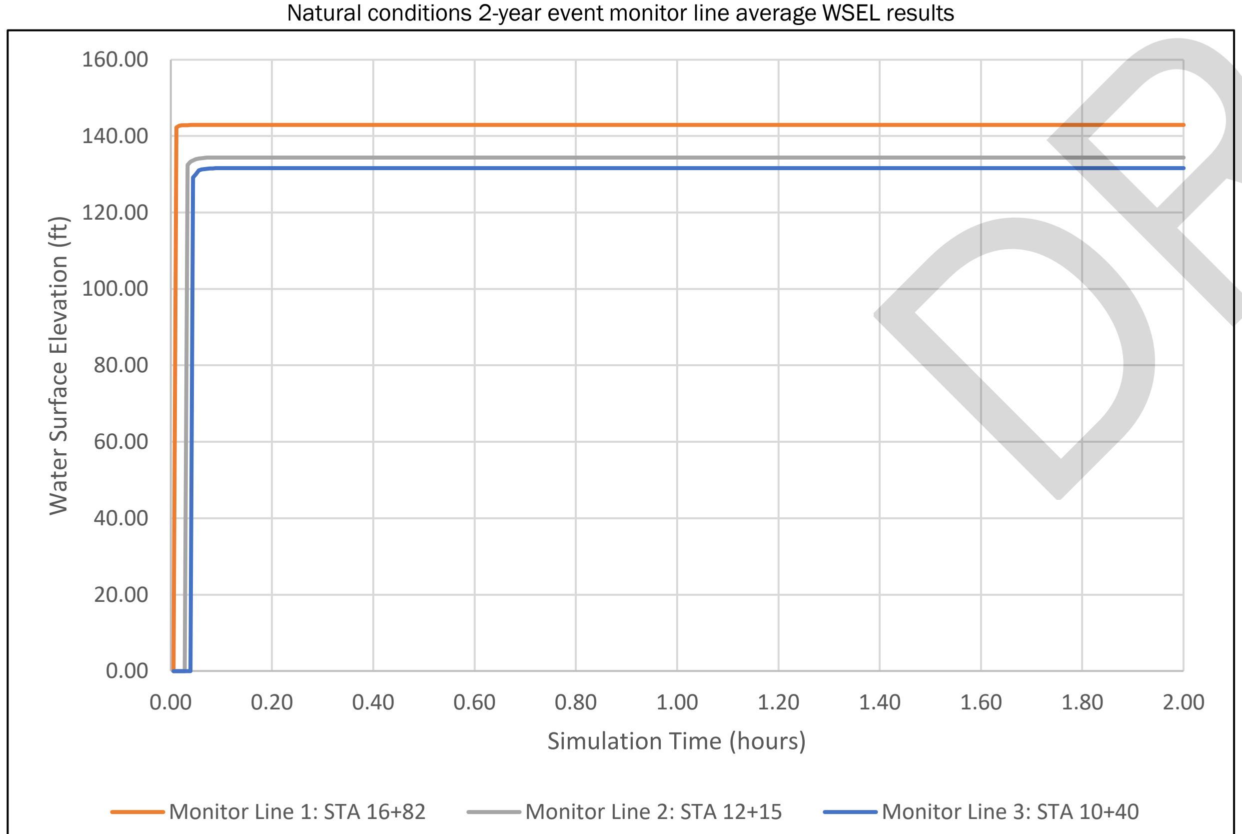
Appendix I: SRH-2D Model Stability and Continuity



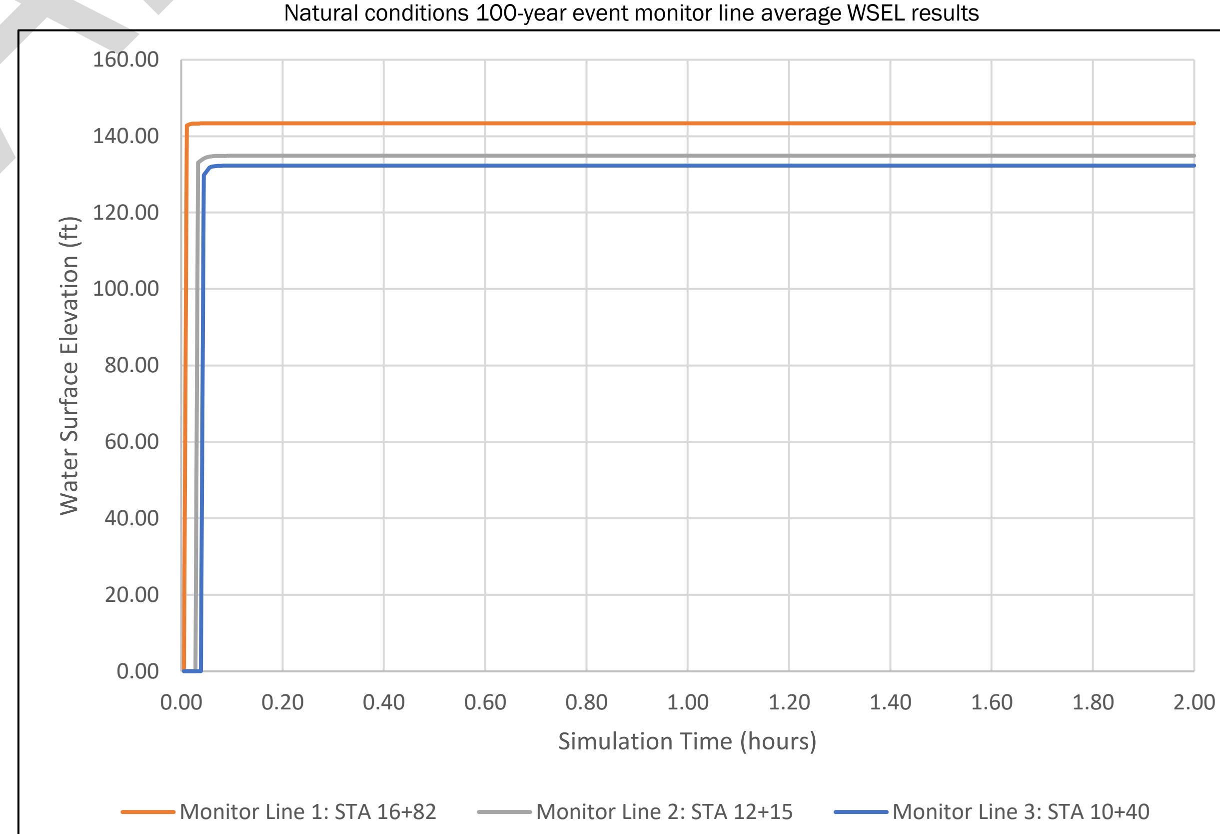
Natural conditions 2-year event monitor line average WSEL results



Natural conditions 100-year event monitor line average WSEL results



Natural conditions 500-year event monitor line average WSEL results

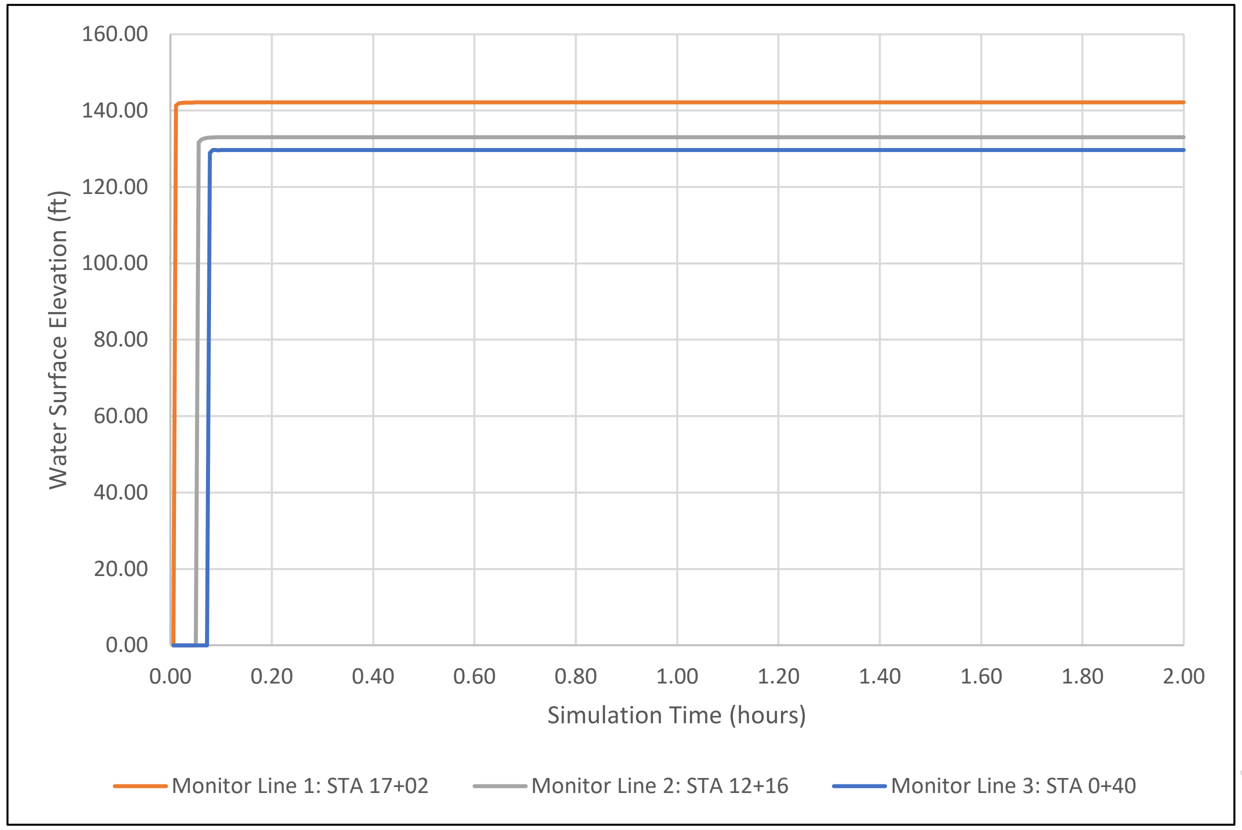


Natural conditions 2080 100-year event monitor line average WSEL results

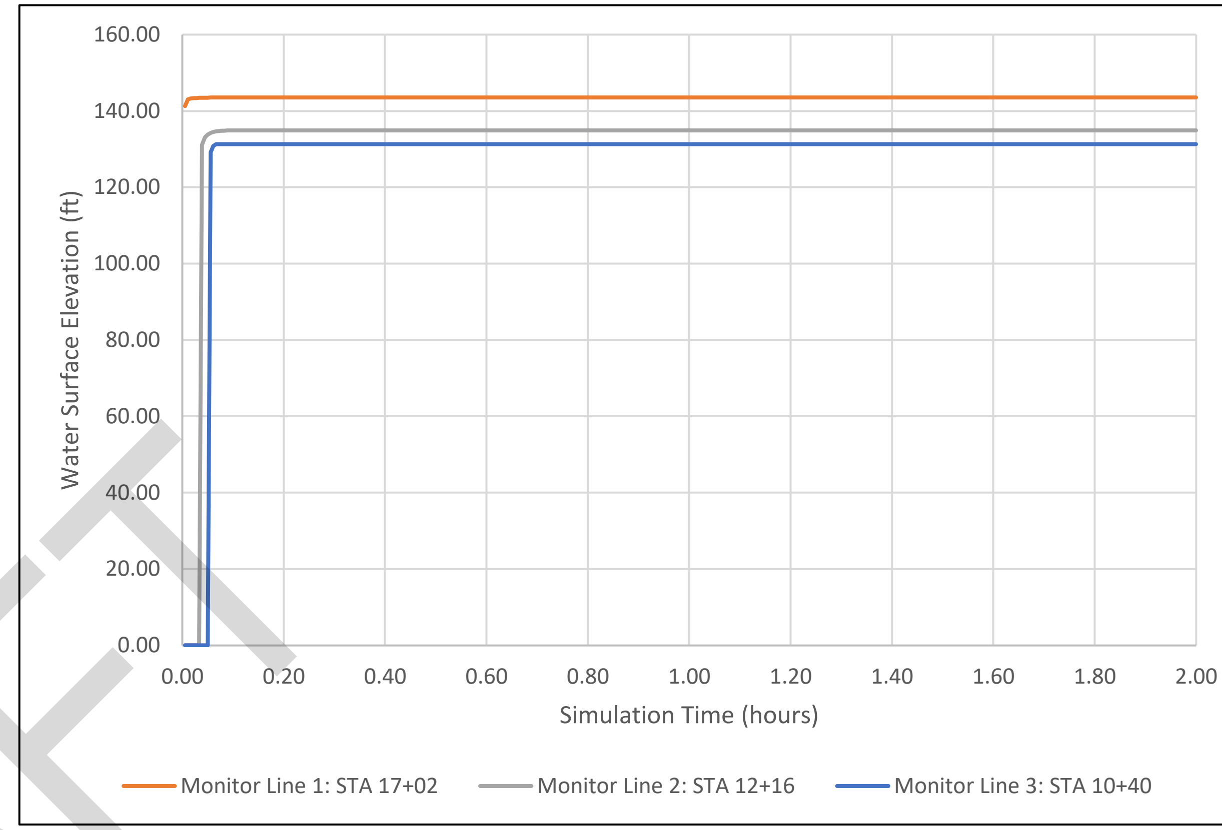
SR 307 MP 1.34 UNT Dogfish Creek (WDFW ID 991999): Preliminary Hydraulic Design: Date Exported: 09/22/2022

Data Source: SMS version 13.1.21 and SRH-2D version 3.3.0

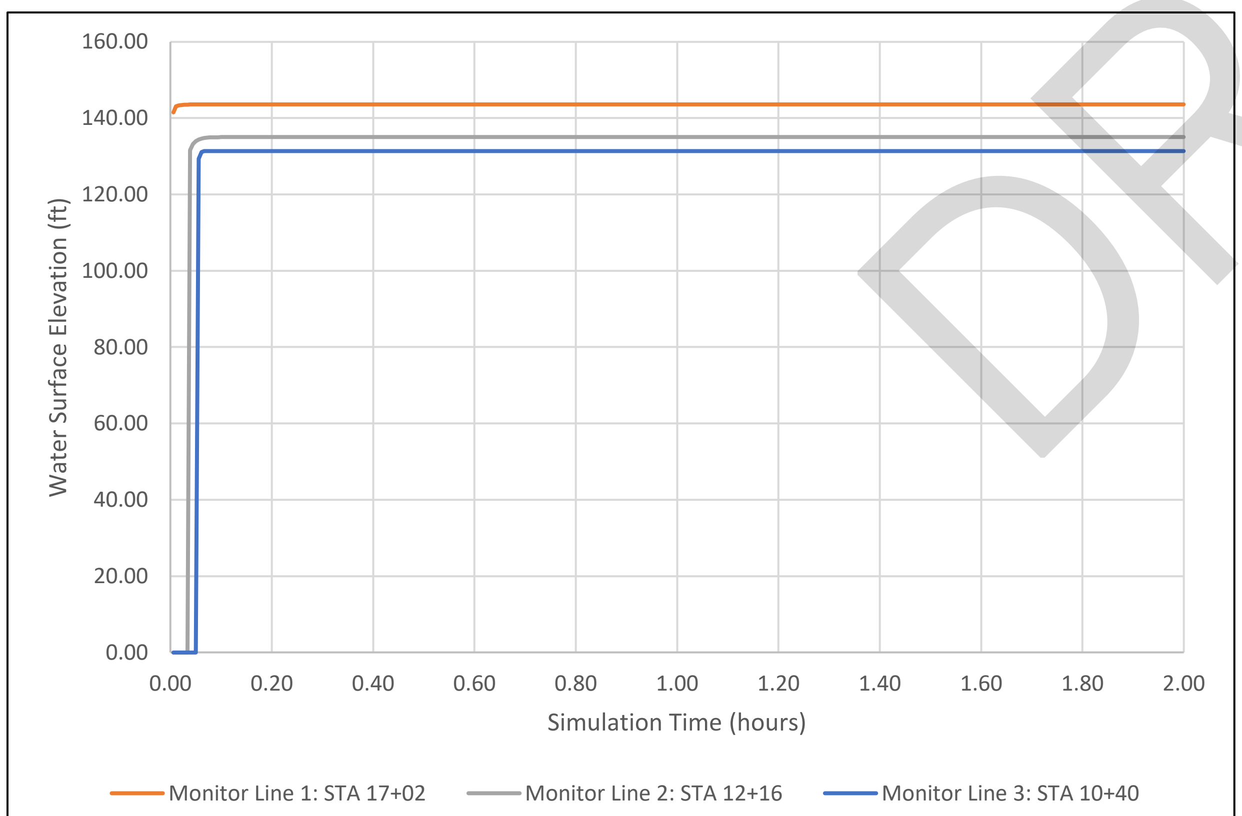
Appendix I: SRH-2D Model Stability and Continuity



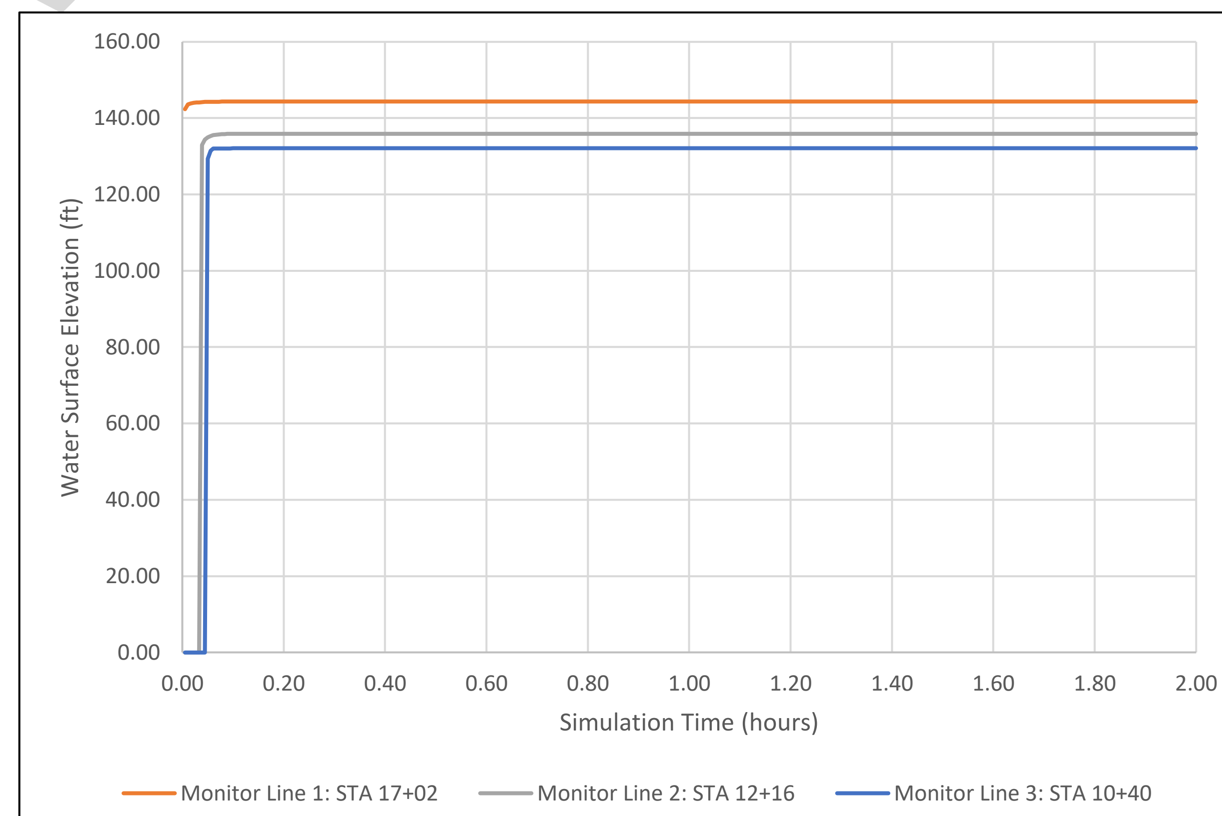
Proposed conditions 2-year event monitor line average WSEL results



Proposed conditions 100-year event monitor line average WSEL results



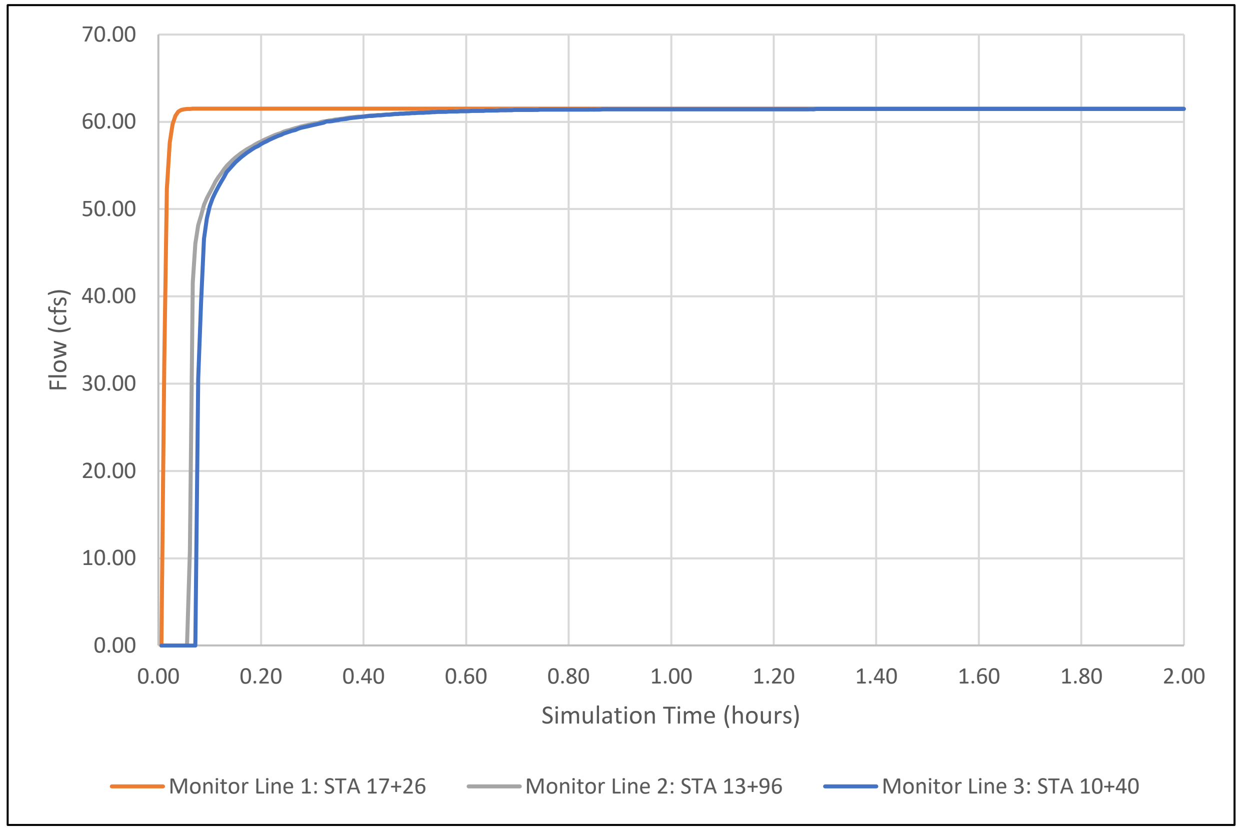
Proposed conditions 500-year event monitor line average WSEL results



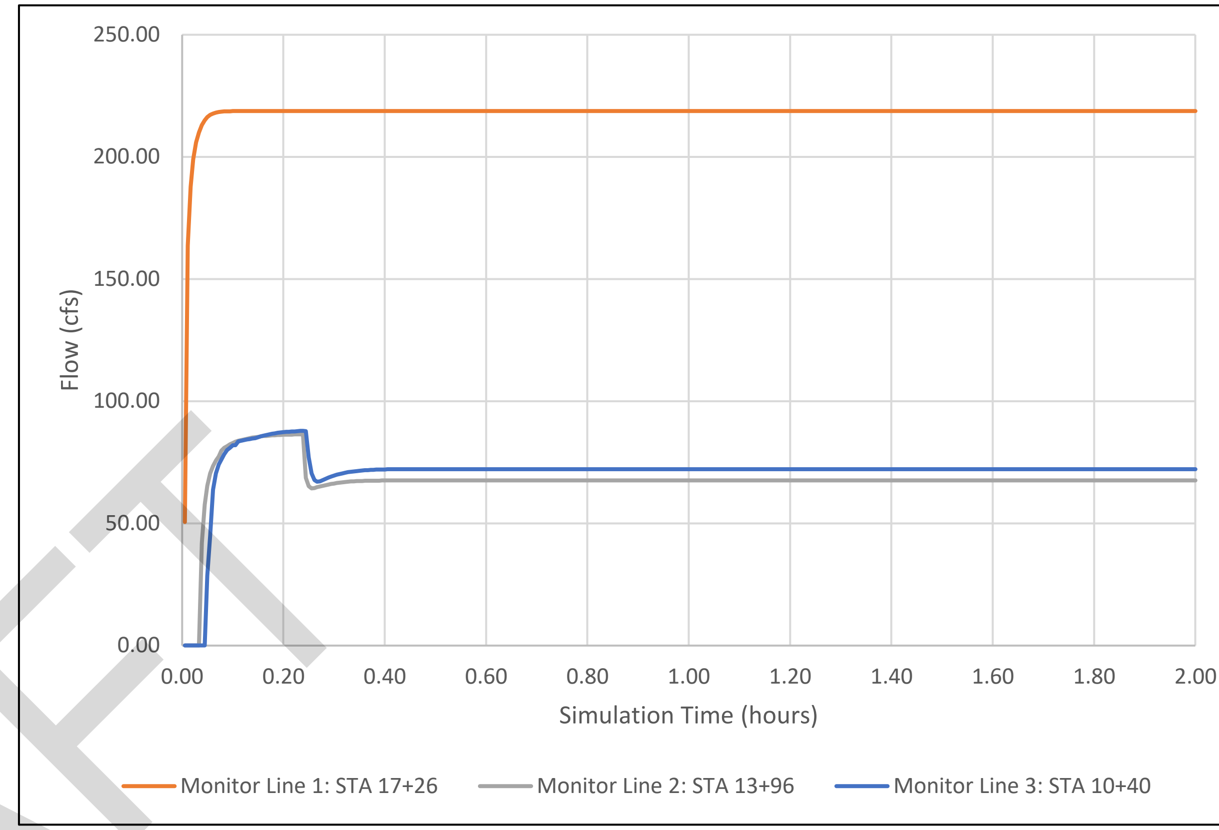
Proposed conditions 2080 100-year event monitor line average WSEL results

Data Source: SMS version 13.1.21 and SRH-2D version 3.3.0

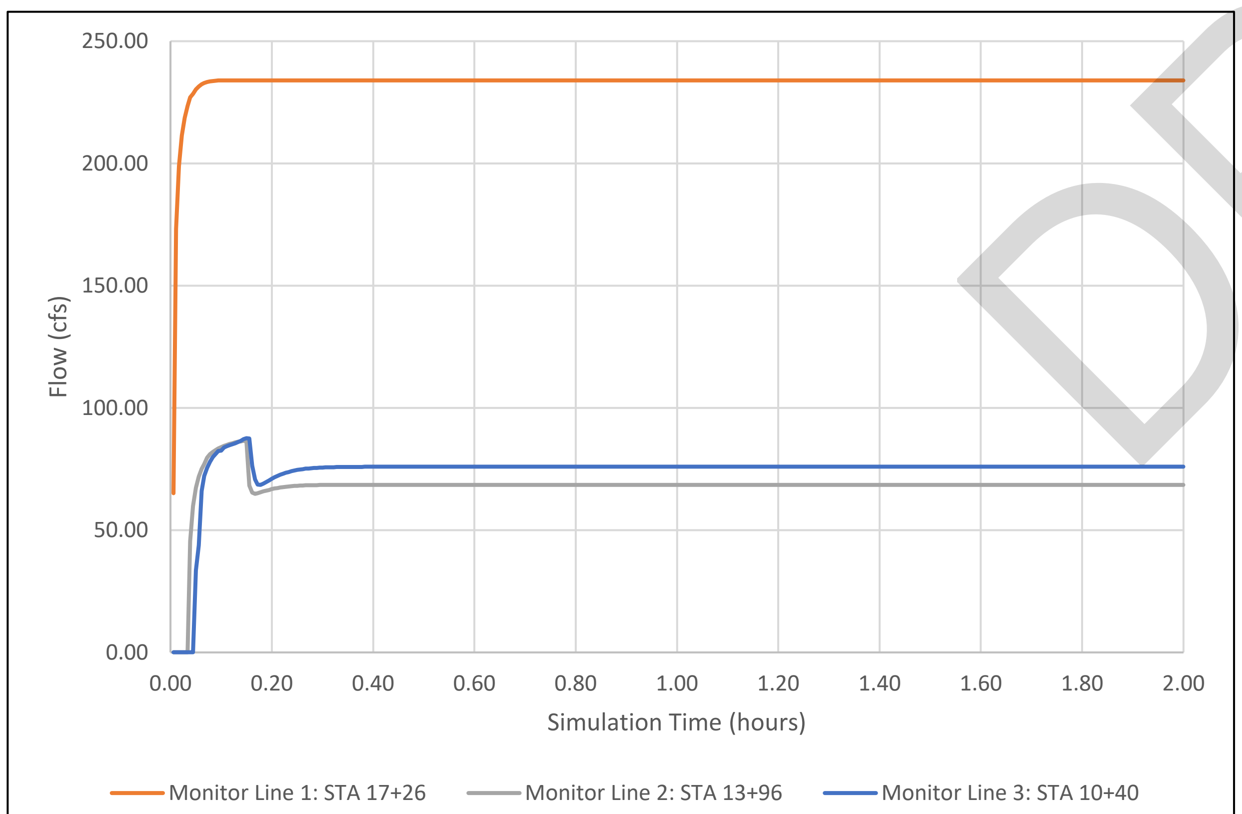
Appendix I: SRH-2D Model Stability and Continuity



Existing conditions 2-year event monitor line flow results



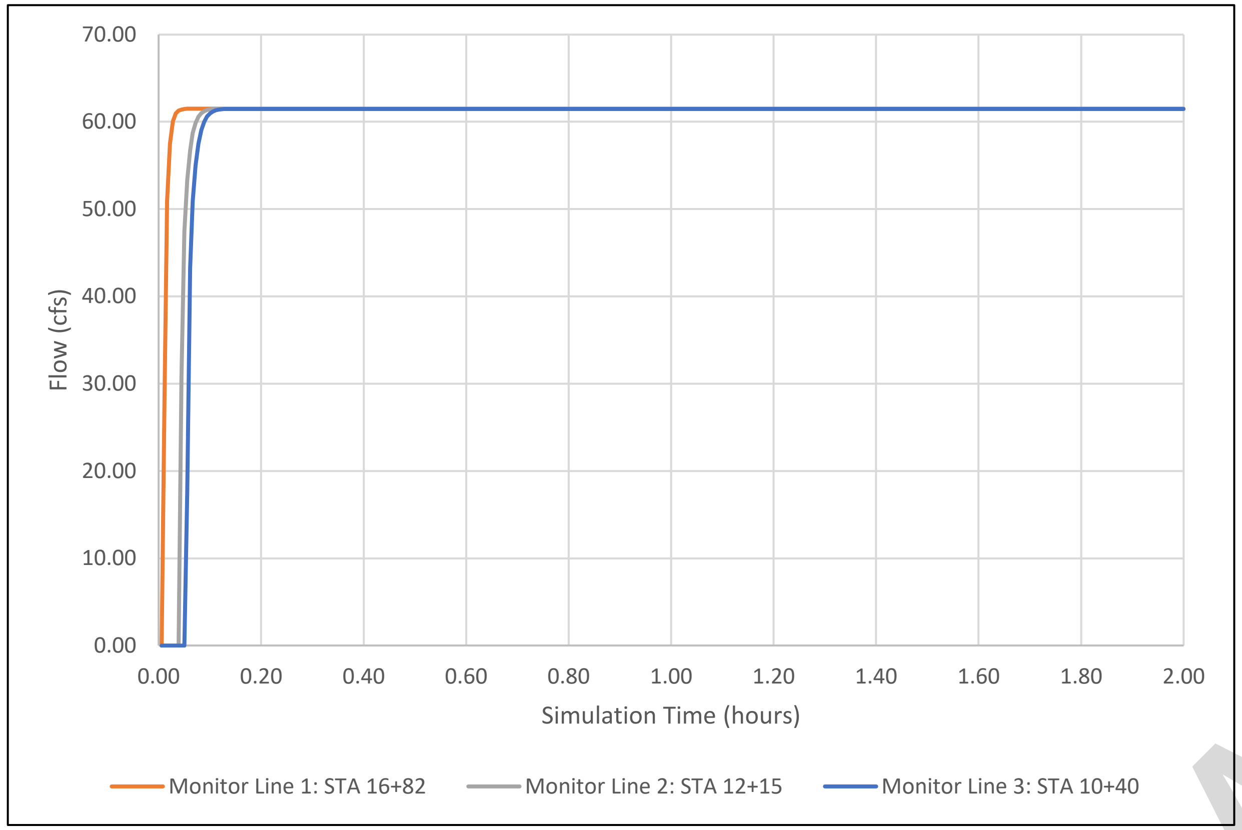
Existing conditions 100-year event monitor line flow results



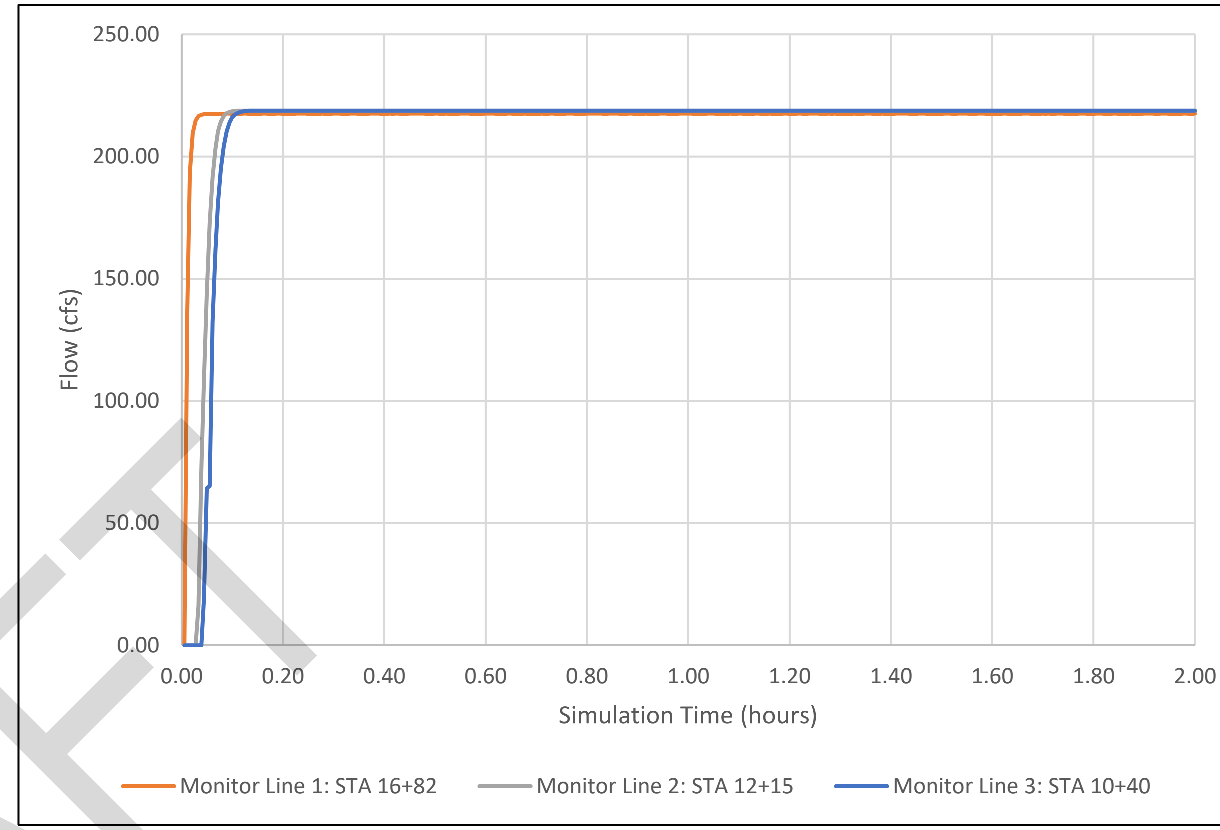
Existing conditions 500-year event monitor line flow results

Data Source: SMS version 13.1.21 and SRH-2D version 3.3.0

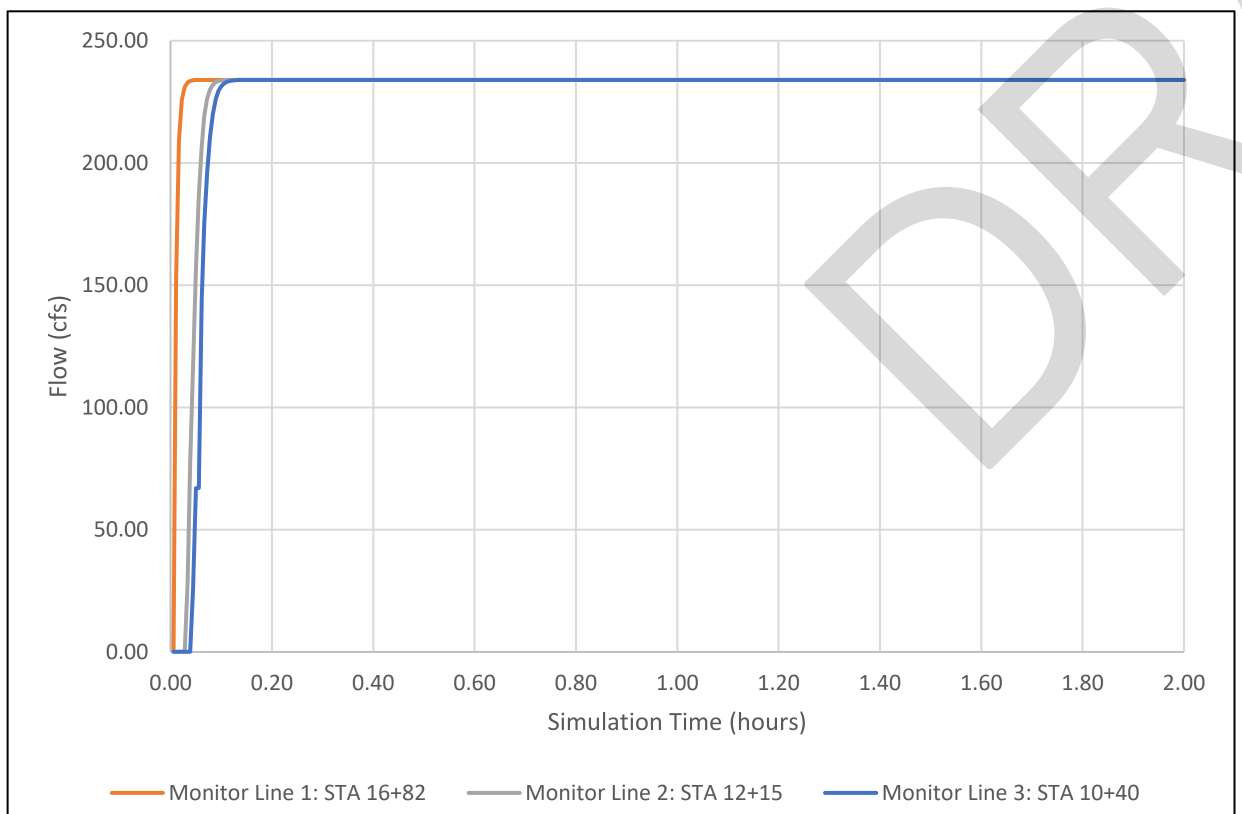
Appendix I: SRH-2D Model Stability and Continuity



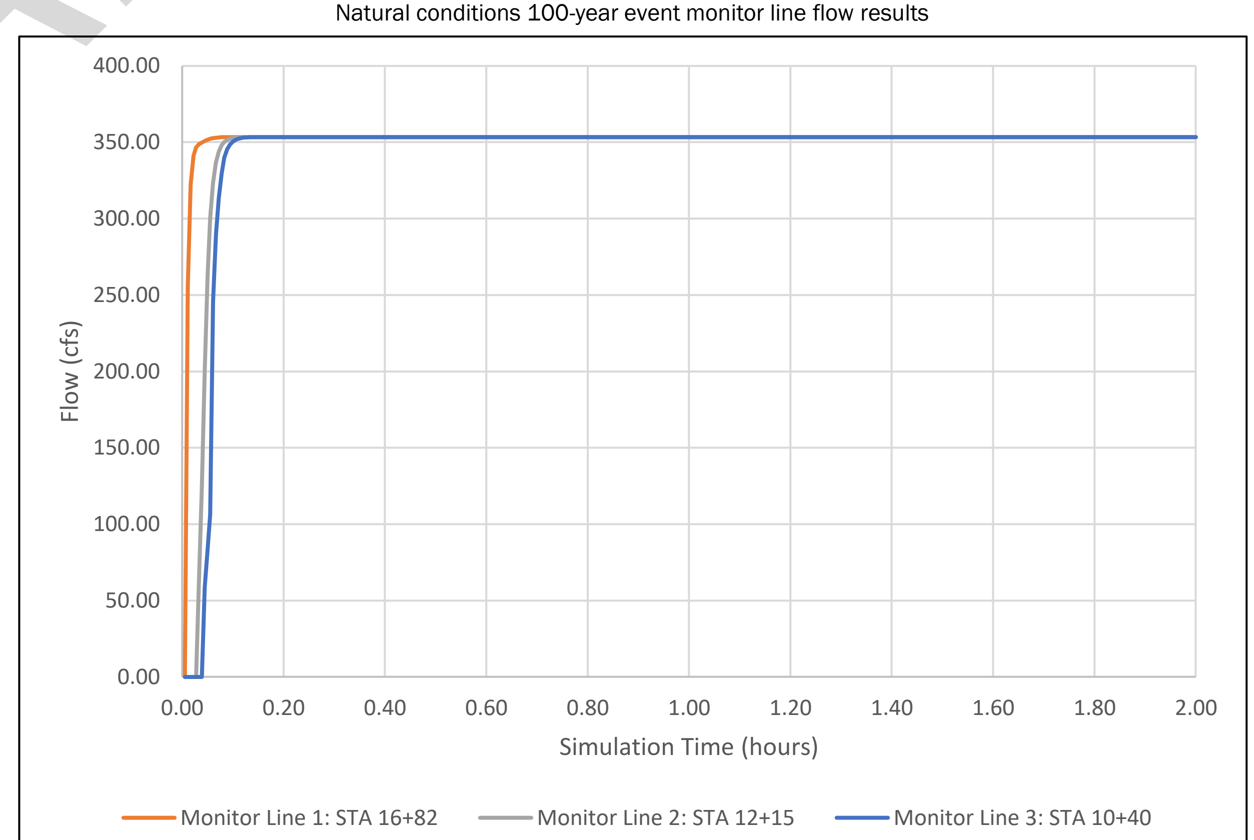
Natural conditions 2-year event monitor line flow results



Natural conditions 100-year event monitor line flow results



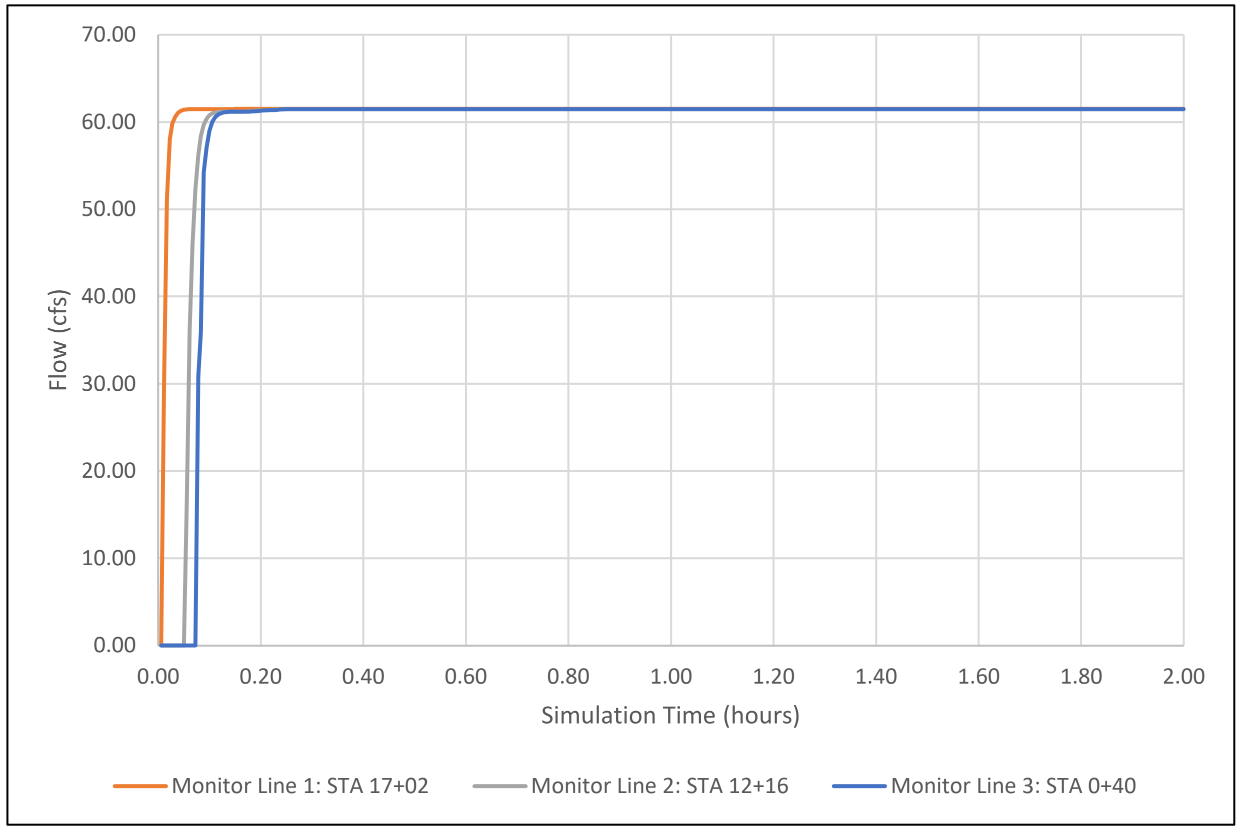
Natural conditions 500-year event monitor line flow results



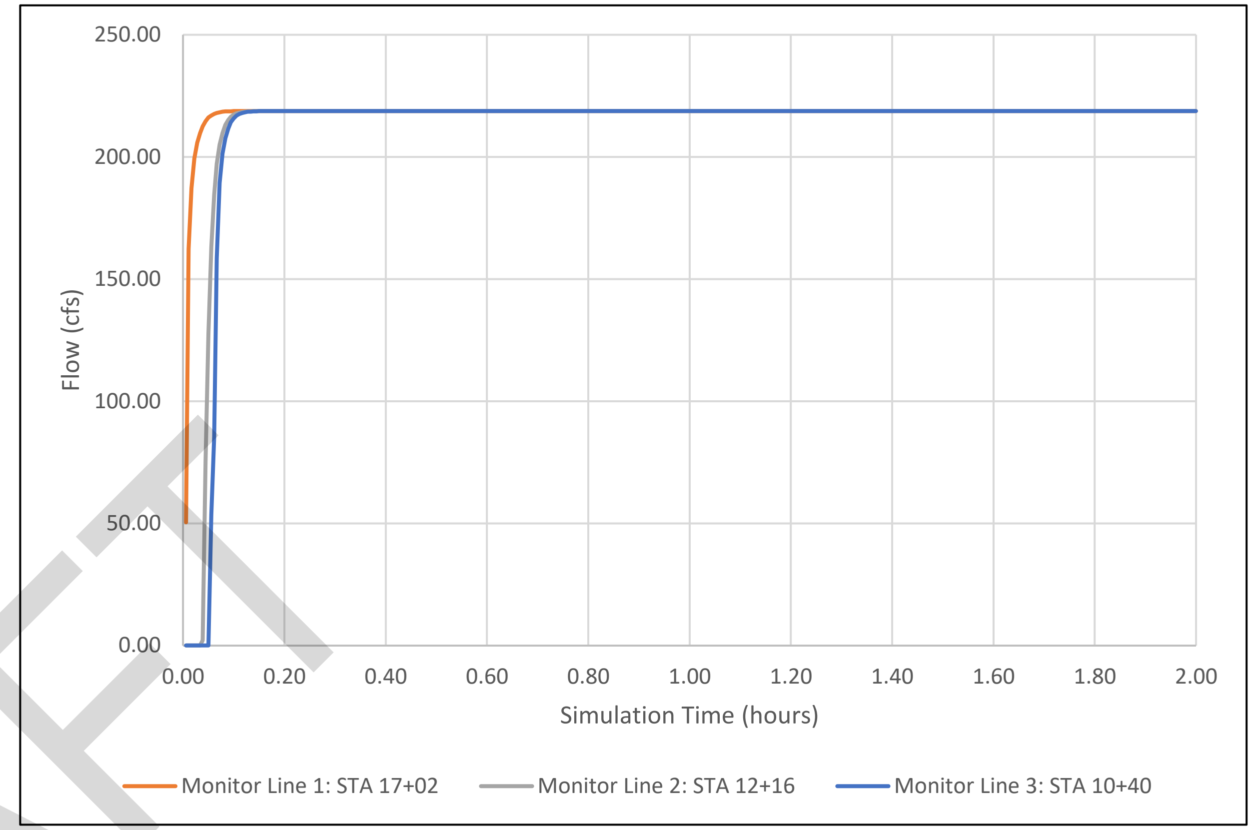
Natural conditions 2080 100-year event monitor line flow results

Data Source: SMS version 13.1.21 and SRH-2D version 3.3.0

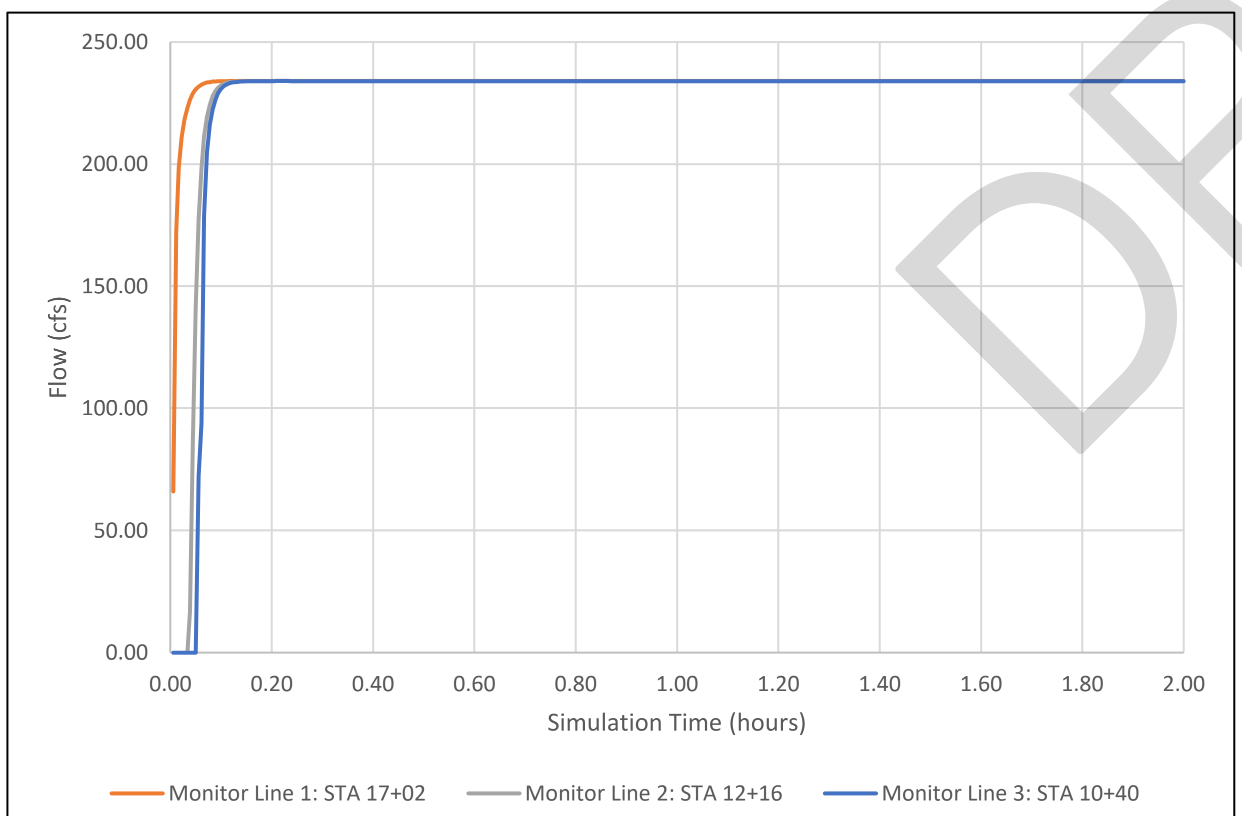
Appendix I: SRH-2D Model Stability and Continuity



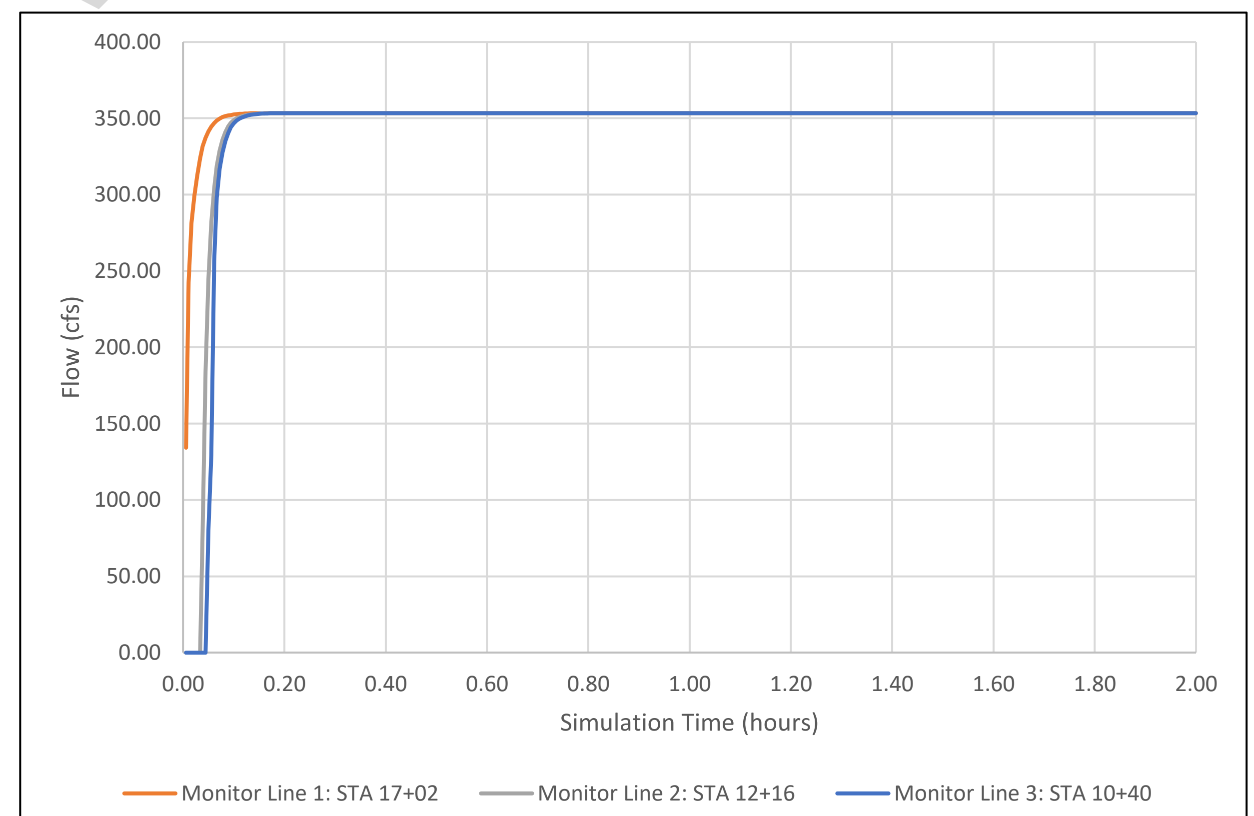
Proposed conditions 2-year event monitor line flow results



Proposed conditions 100-year event monitor line flow results



Proposed conditions 500-year event monitor line flow results



Proposed conditions 2080 100-year event monitor line flow results

Data Source: SMS version 13.1.21 and SRH-2D version 3.3.0

Appendix I: SRH-2D Model Stability and Continuity

Appendix J: Reach Assessment

(This is used only if a reach assessment already exists and has been validated by the hydraulic/hydrology staff to include as an appendix)

Appendix K: Scour Calculations

Contraction and Abutment Scour for All Modeled Flow Events

CONTRACTION SCOUR	2080 100-year	500-year	100-year	10-year	
Input parameters	**Value**	**Value**	**Value**	**Value**	**Unit**
Average Depth Upstream of Contraction	3.9	3.2	3.1	2.4	ft
D50	22.9	22.9	22.9	22.9	mm
Average Velocity Upstream	4.3	4.0	3.9	3.6	ft/s
Results of Scour Condition					
Critical velocity above which bed material of size D and smaller will be transported	6.0	5.8	5.7	5.5	ft/s
Contraction Scour Condition	Clear Water	Clear Water	Clear Water	Clear Water	-
Clear Water Input Parameters					
Discharge in Contracted Section	150.7	113.8	108.7	75.2	cfs
Bottom Width in Contracted Section	8.5	8.5	8.5	8.5	ft
Depth Prior to Scour in Contracted Section	4.1	3.3	3.2	2.5	ft
Results					
Diameter of the smallest non-transportable particle in the bed material	28.6	28.6	28.6	28.6	mm
Average Depth in Contracted Section after Scour	2.9	2.3	2.2	1.6	ft
Scour Depth	-1.3	-1.1	-1.1	-0.9	ft
NCHRP ABUTMENT SCOUR	**2080 100-year**	**500-year**	**100-year**	**10-year**	
Input parameters	**Value**	**Value**	**Value**	**Value**	**Unit**
Scour Condition	Compute	Compute	Compute	Compute	-
Scour Condition Location	Type a (Main Channel)	Type a (Main Channel)	Type a (Main Channel)	Type a (Main Channel)	-
Abutment Type	Vertical-wall with wing walls	Vertical-wall with wing walls	Vertical-wall with wing walls	Vertical-wall with wing walls	-
Unit Discharge, Upstream in Main Channel (q1)	17.0	12.7	12.2	8.6	cfs/ft
Unit Discharge in Constricted Area (q2)	17.7	13.4	12.8	8.8	cfs/ft
D50	22.9	22.9	22.9	22.9	mm
Upstream Flow Depth	3.9	3.2	3.1	2.4	ft
Flow Depth prior to Scour	4.3	3.5	3.4	2.7	ft
Results					
q2 / q1	1.1	1.1	1.1	1.0	
Average Velocity Upstream	4.3	4.0	3.9	3.6	ft/s
Critical Velocity above which Bed Material of Size D and Smaller will be Transported	5.9	5.7	5.7	5.5	ft/s
Scour Condition	Clear Water	Clear Water	Clear Water	Clear Water	
Scour Condition	a (Main Channel)	a (Main Channel)	a (Main Channel)	a (Main Channel)	
Amplification Factor	1.5	1.5	1.5	1.4	
Flow Depth including Contraction Scour	3.1	2.5	2.4	1.7	ft
Maximum Flow Depth including Abutment Scour	4.8	3.6	3.5	2.3	ft
Scour Hole Depth	0.4	0.1	0.0	-0.4	ft

2-Year Bend Scour

Input parameters	Value	Unit
Average Depth Upstream of Bend, D_{US}	1.5	ft
Bend Radius of Curvature, R_C	26.1	ft
W_{us}	12.5	ft
Equation	**Scour Depth**	**Unit**
Maynord	1.2	ft
Thorne	2.4	ft

Equation 1: Maynord Bend Scour (Maynord 1996)

$$\Delta y = D_{US}\left(1.8 - 0.051\left(\frac{R_C}{W_{US}}\right) + 0.0084\left(\frac{W_{US}}{D_{US}}\right)\right) - D_{US}$$

Equation 2: Thorne Bend Scour (Thorne 1993)

$$\Delta y = D_{US}\left(2.07 - 0.19ln\left(\frac{R_C}{W_{US}} - 2\right)\right) - D_{US}$$

Appendix L: Floodplain Analysis *(FHD ONLY)*

Appendix M: Scour Countermeasure Calculations (FHD ONLY)